# ILLUSTRATING RECENT VARIATIONS IN LAND-USE TRANSPORT INTERACTION (LUTI) MODELLING METHODOLOGIES

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## 1. INTRODUCTION

Land-use transport interaction (LUTI) modelling seeks to clarify and explain the often complex interrelationships that exist between land-use and transport. In particular, LUTI modelling attempts to capture and represent the cyclical feedbacks that both fields have on one another and provide professionals with a policy tool to answer these multifaceted questions in a rigorous and consistent way.

David Simmonds Consultancy (DSC) has been at the forefront of LUTI modelling since the mid 1990's. The methodologies described here have all been developed for use with its proprietary land-use modelling software package, DELTA. This paper covers only developments within applications of DELTA as opposed to being a wider commentary about changes in methodologies across the subject field.

In full LUTI models, the land-use model forecasts the locations and quantities of land uses which are passed to the transport model as trip production/attraction quantities. The transport model passes back estimates of generalised journey times which are used to inform how accessibilities in the land-use model change over time. While full LUTI modelling remains the gold standard with the widest potential user-base, variations of it have been developed recently which simplify the overall structure, retaining only the parts relevant to the policy questions being asked.

Typically driven by the end-user requirements (budget/time) along with the availability of data and the existence of a transport model, undertaking appraisal using a land-use model influenced by transport (LUMIT), which removes the interface from the land-use model but retains the interface from transport is now a significant area of work. Other variations of LUTI modelling include the removal of interface from transport to land-use model (TILU model), whereby land-use influences transport but not vice versa. Finally, very recent variations in modelling methodology have sought to isolate the contributions transport and planning make to overall economic and demographic scenarios using a combination of full LUTI, LUMIT and TILU models.

## 2. HISTORY OF DELTA LUTI MODELLING

The development of DELTA grew out of work in the late 1980s and early 1990s on a series of transport strategy studies which used transport models distinguished by a wider range of demand and supply responses than was then typical but with less spatial detail.

One of the issues in those studies was the impact that the transport strategies being tested, some including major demand management interventions as well as transport investments, would have on urban development. In several studies this was addressed by the development "land-use change indicators". This approach involved a static model of activity location applied to calculate changes in land-use as the result of changes in accessibility in a future year.

Whilst “land-use change indicators” proved moderately useful in practice, discussion around their use revealed a growing interest in questions which could only be answered by a complete land-use/transport interaction (LUTI) model, considering both land-use and transport markets within the familiar structure of interacting systems as illustrated in the centre of Figure 1.

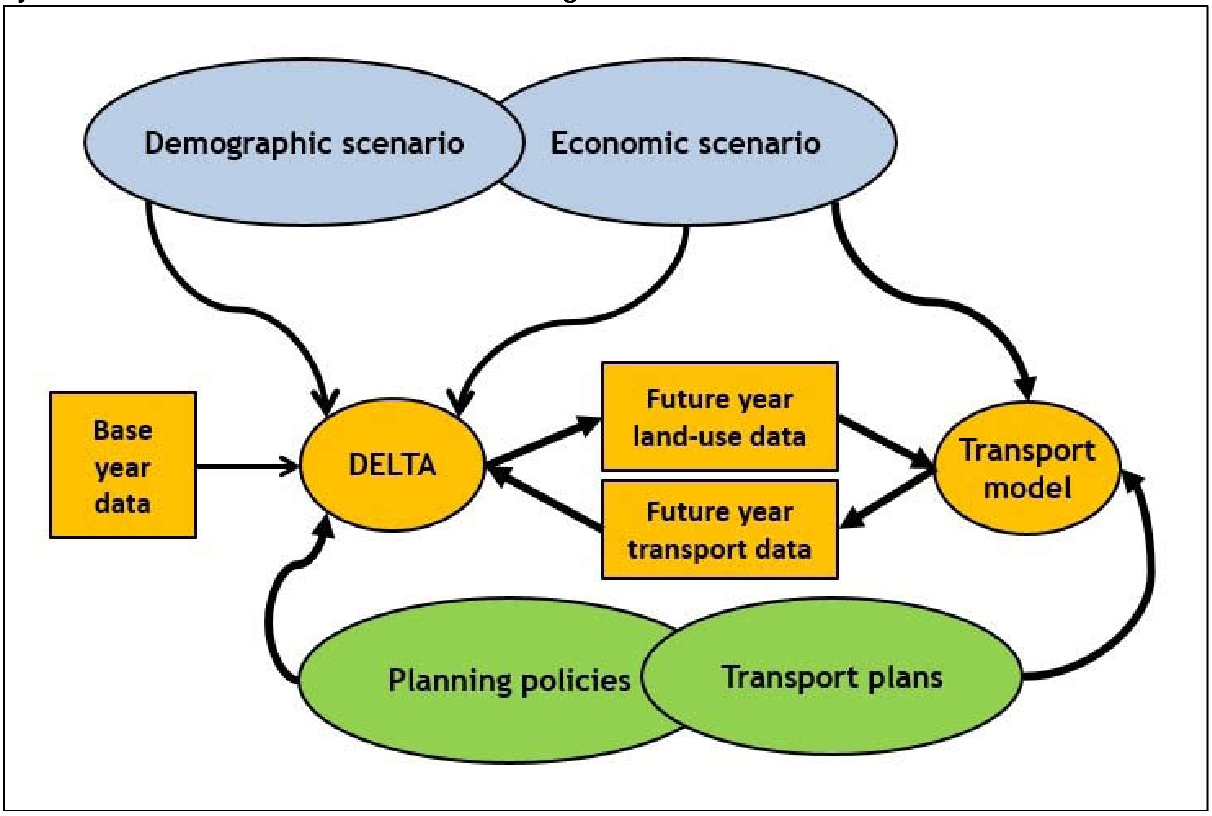

Figure 1 - Land-use transport interaction with scenario and policy inputs

In 1995-96, DSC started investing in the development of the DELTA design and software, and a prototype DELTA application was implemented and linked to MVA Consultancy's existing START transport model of Edinburgh[i]. That transport model was a strategic transport model representing a single future year as conventionally described by "planning data" (households, population, retail floorspace etc by zone for that year); for integration with DELTA it was modified to work at two-year intervals[ii].

The Edinburgh model provided the basis for the Greater Manchester Strategy Planning Model (GMSPM), commissioned by the Greater Manchester Passenger Transport Executive. Two important developments took place within that project: the addition of a car-ownership model, and the implementation of the accessibility calculations within DELTA rather than within the transport model.

A further major round of development followed from a commission to develop a “similar” model for the Trans-Pennine Corridor. The processes represented at the level of an individual urban area could not simply be applied on a large spatial scale (spanning 200km from Liverpool to Hull); so additional models of migration (for households) and of the regional economy (in money terms, but driving the distribution of employment) were developed. The Trans-Pennine Corridor Model was completed in 1999. The overall structure of DELTA has remained broadly constant since then, though all the components have undergone refinement and not all are used in very application. There has however been a big increase in the level of zonal detail represented, facilitated through increasing computational power.

## 3. OVERVIEW OF DELTA MODELLING METHODOLOGY

The initial design of DELTA[iii] was strongly influenced by experience with earlier land-use modelling packages (MEPLAN, TRANUS and the IRPUD models) and both strategic and disaggregate transport models. These influences led to three main requirements for the new package:

- observed data for the base year should be input
- the model itself should work forward over time from that situation;
- the model should work in terms of processes of change

How often the transport model is run is a practical issue and one that relates directly to the variations in methodology this paper addresses. It has not been possible in any application to run the transport model every year - it is just too time-consuming. Nor has any attempt been made to produce an equilibrium model with convergence between land and transport in the same cycle. The practice has generally been to run the transport model every fifth year, as shown in Figure 2. This is less than ideal, since land-uses can change substantially before any resulting congestion is calculated.

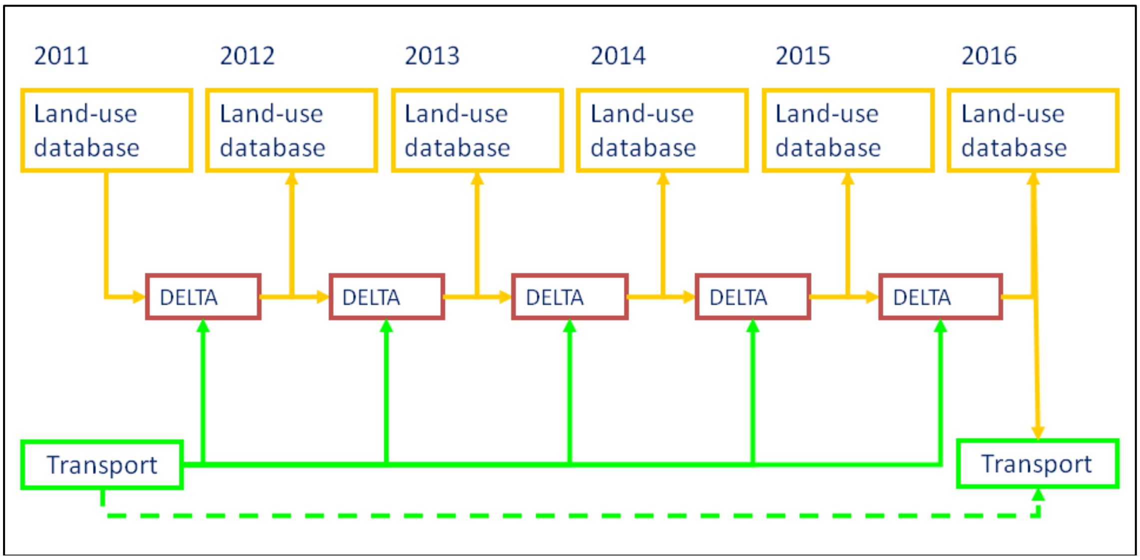


Figure 2 - Time-marching sequence in DELTA, with five-yearly transport modelling

The DELTA package components can be considered in terms of those working on the economy and employment; those working on households and population; and those working on changes in the supply of spaces. The sequence in which they are considered in modelling changes for each year is such that earlier components are preparatory calculations (eg accessibility measures) or consider a part of the system (eg investment) using time-lagged inputs from other parts of the system without no immediate feedback. Later components deal with interactions between components, particularly between households and housing (household location, housing market) between firms and non-residential space (employment location, commercial floorspace markets). This means that the more inevitable effects, or those most strongly influenced by time-lagged effects, come at the beginning of each year's sequence, whilst the most sensitive and rapidly responding are at the end.

The treatment of the economy and employment[iv] operates on two spatial levels, at the upper (macrozones, typically based on travel to work areas) level, firms' decisions about the areas in which to make new investments. The production model forecasts the outturn taking account of the shorter-term changes in the economic scenario, the short-term influences of transport, and so on. Similarly, at the zonal level, the location model represents firms' decisions about where within each area to locate, given the investment decisions and the resulting space requirements, the competition for space and their requirements in terms of accessibility, whilst the final employment outputs forecast the outturn demand for labour given the results of the production model.

The demographic change component deals with change in terms of household formation, dissolution and transformation; households are converted into population later (by the employment/commuting component). It is not intended as a free-standing demographic forecasting method, but only as a way of producing the detail required for land-use/transport modelling given an overall scenario produced by more conventional demographic models.

The car ownership model is based upon the national car ownership model developed by Whelan (2001)[v], converted into a zonal and incremental form. This forecasts changes in households' car-ownership as a function of income, employment, licence holding, car running cost, car ownership cost and company car distribution. Car-ownership is treated as conditional on location.

Migration into and out of the overall modelled area is usually defined as a proportion of each household type that will leave in each period, plus a ratio of arrivals to departures. This formulation allows for different levels of migration both by household type and by socio-economic group. We recognize that migration is often of individuals rather than whole households, and that modelling migration in terms of households is an approximation.

The household location sub-model[vi] is both the "household location/relocation model" and the "housing market sub-model". It works on the subset of households and housing that are in the market in any one year. The process takes account of:

- changes in housing supply (from the development model);
- changes in accessibility (from the transport model and the changes to other land-uses);
- transport-related changes in the local environment (from the transport model);
- housing quality (from the quality sub-model);
- the costs of housing (based on rents adjusted within the sub-model) and the amount of floorspace and other expenditure that households can enjoy given those rents in each zone.

The changes in accessibility, environment and quality are changes over a period of time (one or more modelled periods) ending at the beginning of the present period. The lengths of these periods is inversely related to the frequency of moves for households of each type.

Households are treated as renting a variable quantity of floorspace. As in many other models, a function is used which maximizes the utility that the household can obtain, given its budget and preferences, at the current level of rent. The rent of housing in each zone therefore influences both how many households of each type will choose to locate in each zone, and how much space they will each occupy. The operation of the model involves iteratively adjusting the rent in each zone until the total space "consumed" (ie space per located household times number of households, summed over all household types) equals the space available less the amount less vacant. The vacancy rate varies with the rent.

This employment/commuting component completes the household/population changes by adjusting the employment status of households, and the associated home-work matrices, so as to fill the jobs at each socio-economic level in each workzone. It thus models household members' choices of whether and where to work, subject to matching the demand for labour.

The development model works in three steps, applied separately to each modelled floorspace type. It first calculates the total quantity of development which developers will seek to build, as a ratio of new to existing building. Secondly, this total is if necessary constrained to the floorspace which the planning policy inputs will permit during the year being modelled. Thirdly, the constrained total is allocated to available land in zones using a model with a strong positive relationship to profitability.

## 4. FULL LUTI MODELLING

Full LUTI models of varying size and scope have been developed since the first Edinburgh model described previously. Applications have differed hugely in spatial size and levels of activity and floorspace disaggregation. It is a large task and requires significant investment from stakeholders to build both a transport and land-use model (typically as stand-alone models in their own right) but then also fund the requisite interfaces that automate the communication of data processes so they can be run without manual intervention. The automation of such systems is not absolutely necessary, but is a very useful addition which reduces the overheads of model running and makes use of time outside of typical working hours.

Ensuring the land-use model responds appropriately to the “interaction” based generalised costs and that the transport model is able to run with trips generated from a land-use model that may be (significantly) different from the inputs it was originally built to run with is a sizeable challenge. In fact, both models may operate perfectly reasonably on their own, but through interaction produce very different results, usually producing changes over time beyond the limits of previous calibrations.

The demand for full LUTI models has come from a number of different land and transport planning questions being currently asked. Beyond micro-level transport interventions, schemes being appraised by DELTA are of the scale that failing to consider how households and firms would react over time may grossly under-represent the scheme impacts. This response of actors over time is crucial when looking at the long-term appraisal needed for large-scale infrastructure investment.

That these changes in transport demand can be subsequently fed back into the transport model, providing an alternative future view of the world to standalone equivalent transport inputs, further allowing future generalised costs to take into changing demand on the transport system. In terms of transport scheme appraisal, full LUTI models allow quantification of changes in demand which may influence future scheme design.

In a number of DELTA LUTI models, the transport model is able to include in the interface to the land-use model, auxiliary information which the residential location model can use as a proxy for changing environmental quality. The incremental changes in this variable are fed into the utility of location function, so that increasing congestion (PCUKm) or air pollution (CO/NOx emissions) act as a disutility of location for households in each zone.

In full LUTI models, households relocating in response to improved accessibility from a new highway scheme will offset their utility gains with increasing traffic or air pollution. This is an externality which is separate to the increasing congestion (and impact of that on generalised cost) that should be picked up in the transport model. Transport investments which shift travel toward public transport methods should have additional benefits to households relocating, through reduced congestion/air pollution. This level of detail is incredibly valuable.

Where transport planning practitioners do need to account for changing demand, be it over time or future response to a particular scheme, LUTI models are able to provide a tool which consistently and rigorously appraises all kinds of schemes on fair terms. The time-lags built into the DELTA package, particularly the response of households and businesses to changing accessibility mean without a full LUTI, transport interventions tend to have very typical ten-year responses. A full LUTI model allows longer term responses, as at each interaction year, the resulting generalised costs produced better represent the existing land-use patterns.

Full LUTI runs are further enhanced in the DELTA package through the inclusion of the development model. This means transport and development packages can be tested through the system concurrently and questions around transport supply and demand can be answered at the same time. The development model also allows improvements in transport, improving accessibility and thus residential and commercial rents, to realise planning permissions that were previously unviable. No standalone appraisal of a transport scheme could forecast this, and no standalone land-use model would be able to forecast the likely rental uplift from improving accessibility.

## 5. LAND-USE MODEL INFLUENCED BY TRANSPORT (LUMIT)

The first variation to full LUTI modelling this paper considers is what DSC has termed LUMIT modelling. LUMIT deliberately (or through necessity) breaks the feedback from the land-use model to the transport model, instead using either only base year generalised costs (applied in every year) or including generalised costs from forecast years but from a stand-alone run of the transport model. LUMIT models are often some of the very early runs undertaken en route to a full LUTI model as transport models can have generalised costs available before either of the interfaces are completed.

The model can still be used to test transport schemes added into variant runs of the transport model and included in supplied variant generalised costs. Again, these runs may have already been developed as part of the transport model. LUMIT models clearly do not account for the changing transport demand as a result of land-use relocation. The effect of this change in the model package is shown in Figure 3and Figure 4 below.

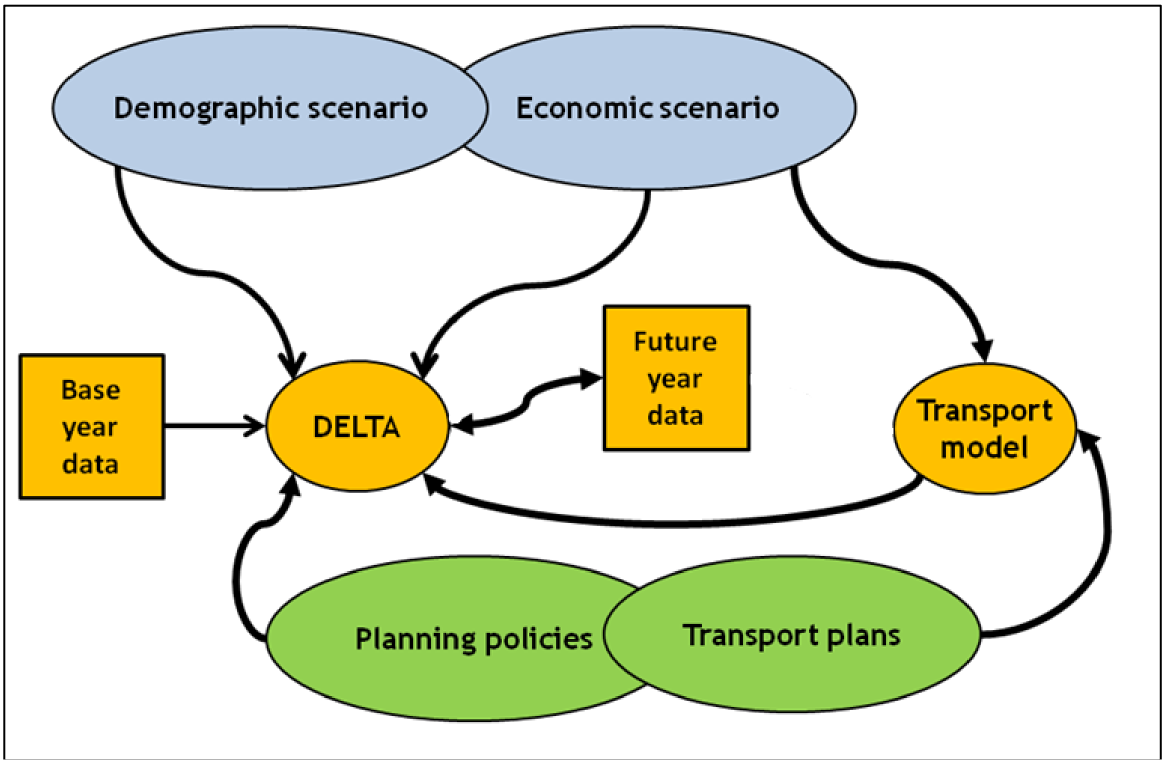


Figure 3 - Overview of LUMIT modelling

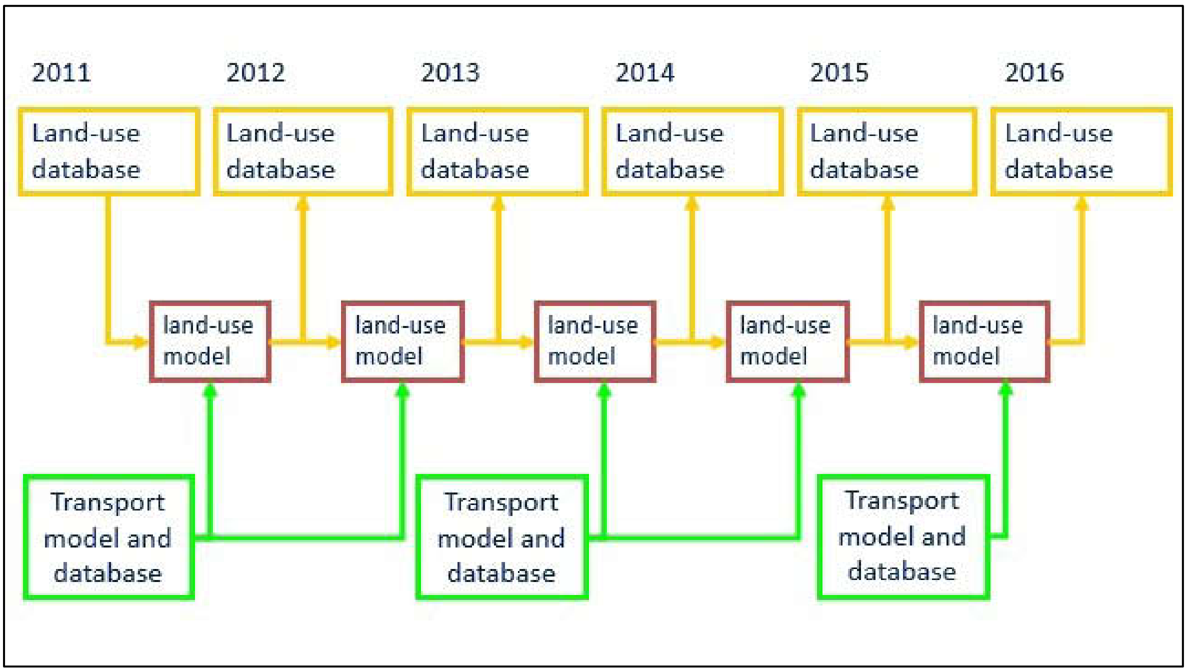


Figure 4 - Time series marching diagram of a LUMIT

Both of the diagrams above show an important feature of the DELTA package, that after the base year land-use database has been completed, each future forecast year is influenced heavily by the preceding years' outputs. Both diagrams also illustrate the key feature of LUMIT runs, no direct feedback from land-use to transport. In the time-series diagram above, varying transport assumptions could be introduced in either the 2013 or 2015 model runs, causing the land-use model to pivot from that point relative to the previous reference case.

A substantial number of DSC projects now involve exclusively running LUMIT analysis, or incorporating it in some form as an interim step towards full LUTI runs. They are always significantly faster to run than full LUTI models because the transport models are invariably the most computationally intensive component. Typically, DELTA runs a single year in around five minutes on a standard desktop PC compared to 13-90 hours for a transport model. Where transport models have already completed a number of runs, the land-use model can quickly be brought into use to give an expanded view of the likely impacts of the scheme.

In applications of DELTA covering the very large spatial areas, a patchwork of transport models may be used to compile a matrix of generalised costs for the modelled area. This can also involve using separate models to undertake highway and public transport modelling. In these applications, it is simply not possible to run the transport models where trip production and attraction data is derived from a land-use model. There may also be constraints related to mis-matches in household/employment categories, zone systems which means converting data for use in the transport model is prohibitively difficult.

The use of transport model outputs for driving land-use models like this has benefits over full LUTI models. In a slightly counter-intuitive way, the simplicity of the setup makes analysis of the results clearer, full LUTI models can be complicated. Because the transport model is run using trip production and attraction data with which it was calibrated, the responses to changing transport supply are likely to be more robust. This of course means the accessibility changes generated through varying transport supply may be more reasonable. The land-use model can, depending on its reference case forecast, overstate/understate transport impacts as a result of the congestion

The effects of accessibility changes within the land-use model become easier to understand as the simpler one-way effect means complicated feedbacks between the two systems are removed. As previously stated, impacts will tend to have relatively predictable ten-year profiles of divergence from the do-minimum equivalent, where after the changes will tend to stabilise. It does limit the ability to analyse transport impacts over the longer term however, which may be crucial for very large investment packages. LUMIT runs also make it easier to identify any potential problems or subtleties about the transport modelling outputs, where using future costs generated by land-use model outputs may cloud such analysis.

## 6. TRANSPORT INFLUENCED BY LAND-USE (TILU) MODEL

When introducing the concept of variations to LUTI models, it was stated that they are driven by variations in the policy questions being asked. TILU modelling is an example of this, where transport planners would like the use of a land-use model to provide trip production/attraction data, but without the cost or complexity of a full LUTI. As the name describes, TILU modelling breaks the feedback from transport to land-use model as shown in Figure 5 and Figure 6 below.

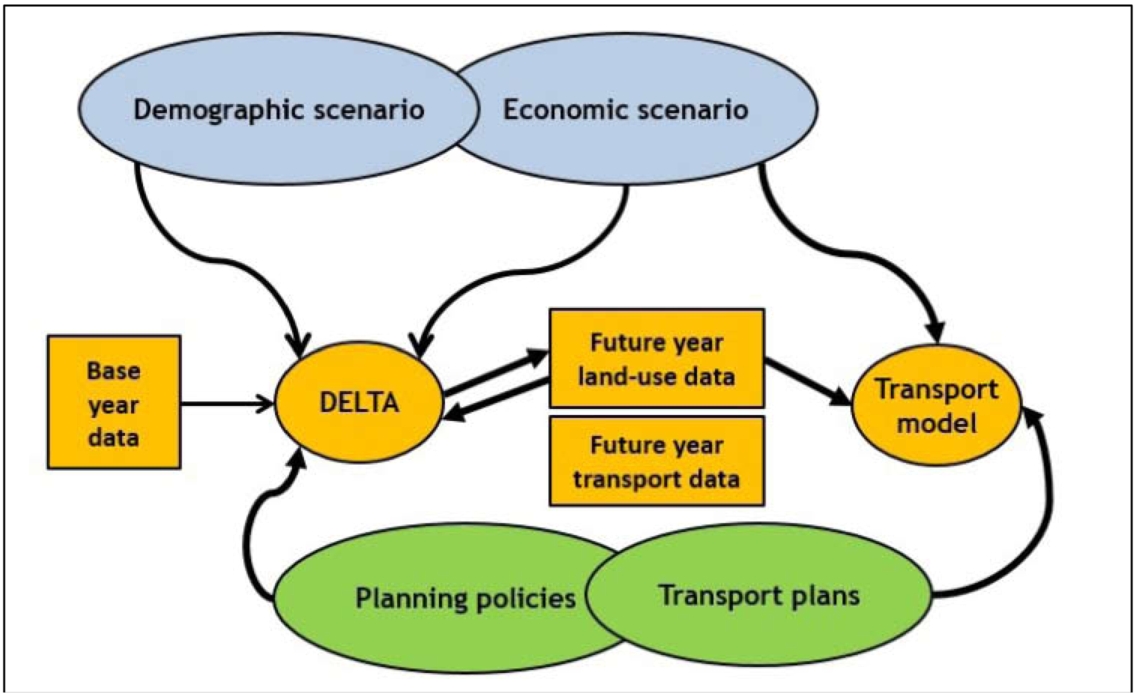


Figure 5 - Overview of TILU modelling

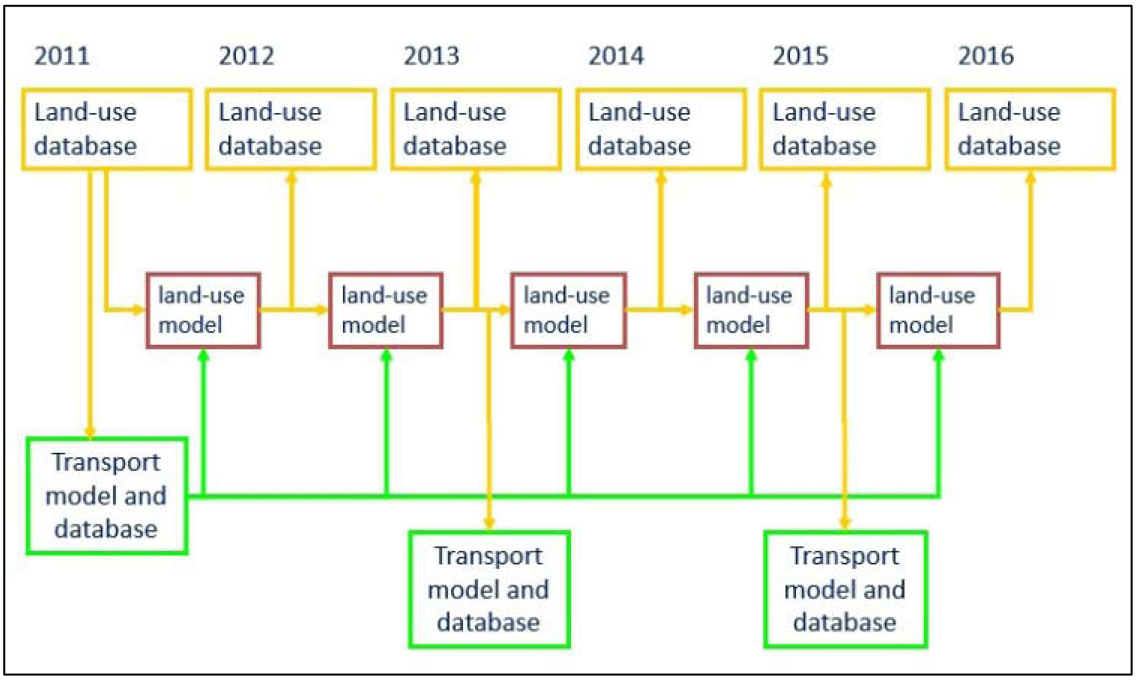


Figure 6 - Time series marching in a TILU model

The two diagrams show the breaking of the full LUTI cycle with the land-use model still supplying outputs to the transport model, but not vice-versa. The land-use model requires at least a single set of generalised costs to produce initial zonal accessibilities, but beyond that, it can run a full forecast with the assumption of unchanging transport supply/demand. In the time-series diagram above, this is illustrated with the base year transport model supply information to every subsequent forecast year.

TILU models again provide a simpler and clearer methodology with which transport appraisal can be undertaken. They also avoid the cost and complexity of developing two-way interfaces. They can provide future year land-use forecasts for use in transport modelling where previously separate forecasts would need to be commissioned. These forecasts can be significantly more disaggregate than other demographic forecasts, allowing wider use in the transport model.

The greatest potential for TILU models is in being able to quickly and efficiently produce a range of potential impacts from transport interventions. All elements of the land-use model (planning policies, scenarios, elasticities) are malleable to the point where they allow users the chance to explore what different feedbacks may or may not be important.

The model only allows changes in the floorspace stock as a result of explicitly permitting it through the planning policy inputs. These are typically assembled through direct contact with local planning authorities or indirectly from published planning documents. They are inevitably always out of date! Planning inputs are deemed exogenous (user specified changes to the floorspace stock) or permissible (potential development if conditions suggest so). Recent applications of TILU models have made use of the development model to look at the levels of transport investment needed, to ameliorate the additional congestion generated through varying levels of development, where differential levels of development draw different land-use responses.

The demographic and economic scenarios control model total levels of households by type, persons by type and employment by sector. Producing a range of scenarios is simple to do and within TILU models, meaning different trip production/attraction data can be specified to the transport model, in a more detailed and robust methodology to simple factoring up or down. This allows the simulation of different realities with which transport planners can begin to look at strategic questions like what overall levels of investment are needed for a given demographic or economic outlook. For specific scheme testing, the impact will also be determined by the land-use model forecasts, so higher growth scenarios with higher levels of congestion/overcrowding would likely see higher levels relief from a given scheme relative to a low growth scenario.

## 7. DYNAMIC ECONOMIC IMPACT MODEL (DEIM)

Land-use and LUTI models have generally being designed to forecast fixed totals, meaning that in each forecast year, the overall quantities of households, persons and jobs is specified to the model and not able to vary as a result of changing levels of other endogenous variables in the model.

In the appraisal of small (relative to the spatial definitions of the model) transport interventions, a land-use model with a fixed total is not unreasonable and relocation as a result of the scheme has no net effects. However, where transport schemes are significantly larger, and may be associated with significant changes in planning policy, the expected levels of relocation of people and jobs are likely to be more significant. The overall structure of the DEIM is shown in Figure 7 below.

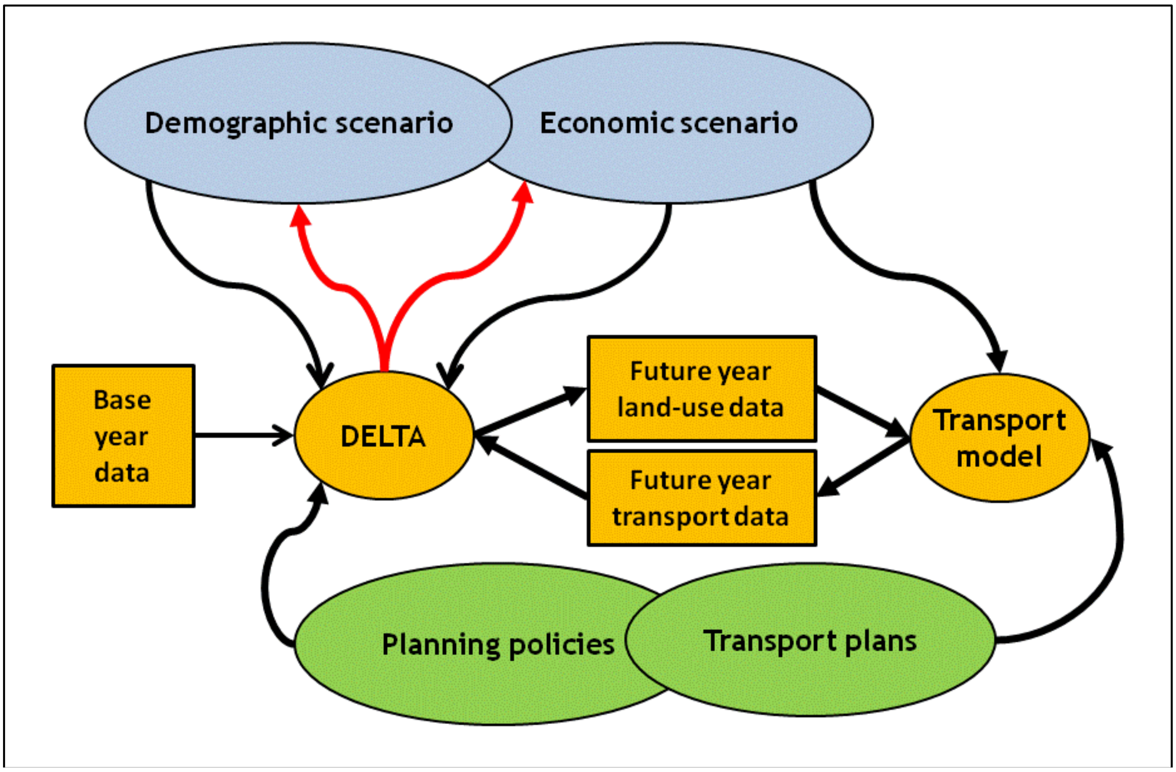

Figure 7 - Overview of the DEIM structure

The key additions to the model here are the red arrows flowing back into the demographic and economic scenarios from the DELTA model, which allows changes in other model inputs to vary the total number of households and jobs in the model over a forecast. In particular, it is the contributions of planning and transport that may allow the economy to grow faster than would otherwise be the case.

The methodology used to produce these net changes has been developed over a number of years and is an evolution of fixed total LUTI modelling. A base case forecast is produced using the land-use model where a given demographic and economic scenario produces known changes in quantities of households and employment over time.

Implicit in this forecast is the idea that the planning system won't constrain or amplify growth, so synthetic (user created) planning policies are setup to grow the stock of floorspace in line with the economic and demographic scenarios. An equivalent task is undertaken with the transport inputs using base year costs which simply scale over time with assumed value of time changes. Again this means implicit in the base case scenarios is the idea that transport supply balances demand, that investment is provided to meet the assumed levels of growth.

A do-minimum reference is subsequently run which uses local planning authority supplied planning inputs (real instead of synthetic) and transport model outputs produced as part of a full LUTI forecast, with generalised costs reflecting do-minimum changes in transport supply mixed with changes in demand as forecast by the land-use model. Where the planning system fails to supply enough land to development, rents will rise above base case levels. Similarly, where transport supply is not sufficient to meet rising demand, congestion and overcrowding will result in higher generalised costs and lower accessibilities relative to the base case.

The model as currently designed produces variation in the net economic totals as a result of differences in access to economic mass relative to the scenario matching base case. Both the planning and transport systems in the model may contribute to higher levels or, constrain to lower levels of access to economic mass. The rationale behind this pivoting functions draws heavily of research done by the Spatial Economics Research Centre (SERC) for the Northern Way[vii] which evaluated how agglomeration of economic activity can raise the productivity of an area.

The DEIM approach has not so far been extended to forecast how net changes in the national economy will affect inward and outward migration, though the methods used at regional or sub-regional levels could quite reasonably be applied at national level (with different sensitivities). The model does represent the interactions between employment and households through the supply and demand of labour. In making investment decisions firms are sensitive to the wage implications of areas with high housing costs and poor transport systems. As such, areas which smartly align aspirations around economic growth with the planning and transport systems see higher economic and demographic growth through drawing activity in from other areas and improvements in productivity resulting from higher levels of access to economic mass.

## 8. CONLUSIONS

The variations in land-use modelling methodologies discussed here highlights the ever changing demands being made of land and transport planners. Methodologies are constantly evolving to be best placed to answer the sorts of questions being asked. The variations discussed in this paper show just how flexible LUTI modelling, as a broad field, can be. It is worth restating that full LUTI models remain the gold standard and that the different methodologies highlighted can be completed by branching away from an existing full LUTI model for a specific package of testing with some additional unavoidable constraints.

In particular, the latest developments described in the dynamic economic impact model methodology are a long standing feature request from clients that have only recently come to public prominence in relation to the findings of the Transport Investment and Economic Performance (TIEP) paper[viii]. Pre-TIEP, users of land-use models of all spatial scales inevitably began to ask questions about what levels of transport investment required thinking beyond the model boundaries. One simpler (in some ways) response is to keep pushing the boundaries of the modelled area ever wider. For city and sub-regional areas this is simple to do, but DSC now operates a number of Great Britain level models.

The DEIM methodology of producing net levels of economic change through varying productivity is still in its infancy but has produced encouraging results. Post TIEP, planners and transport appraisers are now far more conscious of the contributory and transformative impacts of transport investment and so the limits of fixed total LUTI modelling had to be pushed to something more dynamic and responsive.

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