1. INTRODUCTION

Land-use and transport interaction models are appropriate instruments to forecast land-use responses to transport change. Such models are dynamic in structure, and iterate between transport and land-use components to model how the system evolves over time. The essence of a Land Use and Transport Interaction (LUTI) model is the two-way interaction between land-use and transport. The land-use sub-models generate social-economic changes by zone, input for the transport model, and the transport model generates accessibility indicators as input for the land-use sub-models.

This research presents the development of a land use component of the Generic Urban Models (GUM) Phase 2 project, sponsored by the UK Department for Transport (DfT). The land use component is part of a forecasting model for the Leicestershire region in the UK. In addition to the application of the model for the Leicestershire County Council, the generalised approach can be used by the UK Department for Transport to test impacts of transport policies and exogenous developments on larger, non-metropolitan, urban areas throughout Great Britain.

The land use component of the GUM model is based on the TIGRIS XL model, an integrated land use and transport model that has been developed for the Transport Research Centre in the Netherlands. The GUM land-use model uses discrete time steps of one year to generate population segmentation and employment figures by zone. An integration is made with the Central Leicestershire Transport Model, through the impact of transport on the core modules, namely the housing market and labour market modules. These modules include the effect of transport changes on residential or firm settlement behaviour and link changes in the transport system with changes in land-use. A land and real estate module simulates supply constraints based on the inputs of available land, land-use policies and projected construction. The module defines different levels of government influence, ranging from completely regulated to free market policies. Various feedback loops between demand and supply are available. A demographic module is included to simulate demographic developments at the local level. The model output can be constrained to ensure consistency with existing social-economic forecasts at the regional or national level.

The paper presents a short description of structure of the GUM land use model and its main features and the interaction with the transport model. The options to specify distinctive land-use policies are addressed as well. Work on the development of the GUM land use model is still ongoing: test runs are...
being performed to explore the possibilities to implement different land use policies.

2. POLICY BACKGROUND

General objective of the GUM project is to build a set of policy models to evaluate the synergy between combinations of detailed local transport policies for different urban areas in order to achieve national reductions in congestion or other targets. The GUM model has been developed for the Leicestershire area, which serves as a typical large, non-metropolitan, urban area in the UK. Generalisability of the modelling framework is an important requirement to the GUM model.

The GUM model includes a land use model that simulates land use responses to changes in the transport system. Such a land use model distributes household and employment totals - and corresponding production & attraction trip ends, for passengers and freight. The model needs to represent transport responses to land-use change as well: for instance the impact of a planning policy that concentrates new development in particular parts of the urban area on the production & attraction in the transport model.

The GUM land use model is designed to provide support to urban clients and DfT in building a vision on spatial development and its interactions with the transport system. The GUM land use model can address the following policy issues:

- Land-use effects of transport policies, including infrastructure, as well as pricing policies. The structuring role of transport on the settlement pattern of residents and employment is important for assessing spatial development in line with the spatial targets and assessing economic impacts of transport measures;

- The long-term impacts of transport policies on the transport network, e.g. measures to improve accessibility leads to location of new activities, new activities leads to new transport demand and new transport demand leads to new congestion problems;

- Effects of long-term socio-economic scenarios on transport and land-use;

- The impacts of spatial policies on the transport system. In principle this can be analysed with a standard transport model, however there is often a big gap between land-use policies formulated, for example as zoning or revitalisation policies, and the detailed population and household segments needed as input for the transport model. LUTI-models can bridge this gap between the spatial plans and required input to calculate the transport effects;

- Effects of alternative land-use policies, including various degrees of market regulation, on land-use and transport. This analysis includes the influences
of non-government actors like residents and firms on the spatial development. The model is capable of modelling the preferences of the actors and their influence on spatial developments.

3. DESCRIPTION OF THE MODEL

Integrated land use and transport interaction models have a large variety in specification. A range of approaches are outlined in Webster et. al. (1988), Miller et. al. (1998), DSC and ME&P (1999) or Wegener and Fürst (1999).

An important characteristic of LUTI models is the linkage between the housing and labour market. Since Lowry’s Metropolis model (Lowry, 1964) many models (MEPLAN, TRANUS) have distinguished a basic exporting sector and a service sector. In a hierarchical approach first the basic sector is allocated, next the population and finally the service employment. Such a structure is increasingly inappropriate because of the dominant position of the service sector, the growing share of inactive population and the stronger position of employees in our current economies. The pre-assumed relationship between location choices of jobs and people needs to be replaced by a complex mixture of mutual influences. In the GUM model the mutual influence of population- and employment location is modelled by linking location attributes in the location choice models on the housing and labour market.

The time dynamics are another important feature of LUTI-models. The GUM land-use model is designed as an incremental growth model, comprising of modules that are not necessarily in equilibrium. An incremental approach takes the state in the previous simulation period as starting point and simulates the changes to this state that apply in the current period. This is fundamentally different compared to a general equilibrium approach where all labour and population is redistributed each time step. An incremental approach is preferred for two reasons. First of all it is very unlikely that a general equilibrium state is reached in the base year or any simulation year, because of the long response time of land use developments. An example is the slow response time at the real estate market to changes in housing demand. A second argument for an incremental approach is that it is very unlikely that equilibrium is reached because of exogenous factors, such as demographic change or regional economic development.

Another important feature of the GUM model is its modular set up, which offers a few practical advantages. It keeps the model more understandable, takes advantages of the best estimation/calibration options by sector, and is more open to future improvements. An important requirement to the GUM model is the incorporation of all relevant modules in the land-use component that as such offers a flexible and well-structured framework for any future changes or extensions.

The model has not been set up to model all spatial planning processes as in depth endogenous modules and so the following processes are implemented exogenously:

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- Modelling of interregional migration of households: the land-use model will cover the area of Leicestershire and competition between regions is not included. The TIGRIS XL model in the Netherlands offers such functionality, but this feature is outside the scope of the GUM project;
- Economy: the total number of jobs and household incomes within the region are assumed to be unaffected by changes in the transport system. The model only addresses distribution effects and neglects generative effects.

**Modules**

The land use model incorporates four specific components: a demography module, a land-use and real estate market module, a housing market module and a labour market module. Figure 1 gives an overview of the model's architecture and the modules it comprises, their interdependencies and the interactions with the transport model.

![Figure 1: Overview modules and interactions in the GUM land use model](image)

- **The demographic module**: The demographic module addresses the transition processes of the population and households. The module determines persons by category (gender, age), households by category (size, income, etc.) and the labour force at zonal level. In addition to accounting for demographic transitions (e.g. aging, birth and deaths, and in and out migration), this model distributes the migration flows calculated in the housing market module.
The demography module ensures consistency between households and persons categories for all the zones.

- **The land-use and real estate market module:**
The land market module processes changes in land use and the development of new residential and industrial locations. The role of the government in the land use developments can be implemented through various input files and switches for the level of land market regulation. First of all, known land use plans can be implemented exogenously through scenario files. For the remaining, long-term, land use developments the level of market regulations can be varied between a regulated land use planning system to a free market. A setting where land use development for an entire region is completely regulated and state-driven seems unrealistic for nearly all model applications, though certainly subregions may be highly regulated and/or protected from development, such as a greenbelt. One of the advantages of the GUM land use model is that different sectors of a region (and even specific zones) can take different development “settings”.

- **The housing market module:**
The housing market module simulates the annual moves (if any) of households. It simulates two choices: the choice to move or stay and residential location choice, conditional on a move. A wide set of explanatory variables are used in the choice models, such as household characteristics, neighbourhood amenities, prices and accessibility. Accessibility is taken from the transport model in the form of logsums, providing a direct linkage between the two models. These measures are household type specific and combine mode and destination effects in a consistent way.

- **The labour market module:**
The labour market module first models the changes in number of jobs by sector and changes in the workforce at the regional level. Next it allocates these changes to zones based on location factors, such as the distribution of industrial areas or office space. The structural economic development of the whole study area is exogenous input to this simulation. The labour market module is segmented to seven economic sectors to account for differences in location behaviour between sectors. The spatial distribution of employment is affected by changes in other sub models within the GUM land use model, such as demography, land and real estate market, housing market and transport market. The influence of accessibility on the spatial distribution of employment is of key interest for this research and the labour market sub-model can be used to model the structuring effects of transport measures on the spatial distribution of employment.

**Flowchart of the GUM land use model**

The incremental structure of the module implies that within each time step the different modules are executed subsequently where the input for a module is
provided by output in the previous time step or by output from the other modules in the same time step. Figure 2 gives an overview of the interdependencies between the modules across the different time steps. The Demographic- and Land use and real estate modules are executed first. These modules use exogenous scenario data (birth and death ratios and spatial planning policies) and output from other modules in the previous time step. The Demographic module uses the spatial distribution of persons and labour participation from respectively the Housing market- and Labour market modules. On a 'free' land market setting, the Land use and real estate module allocates new dwellings proportional to a local surplus in dwelling demand, computed in the housing market module in the previous time step.

The Housing- and Labour market modules use the output from the Demographic- and Land use and real estate modules in the same time step. The Land use and real estate module specifies the dwelling supply at the housing market and the supply of firm locations at the Labour market module. The Demographic module provides the population- and household composition at the housing market and the potential labour population for the Labour market module. Next to that, the choice models in the Housing- and Labour market modules use accessibility indicators from the transport model as input.

Figure 2: Flowchart of interdependencies between time steps
Interaction with transport model; use of accessibility indicators

The Transport model has a specific position in the modeling system. Due to practical trade-offs (e.g. running time) the transport model is run only once for every 5 time steps. Accessibility indicators do not change rapidly over time; hence it seems acceptable to run the transport model with a disaggregated time frame. However: if desired, the transport model can be run with the same time step as the land use model or it can make a run for any desired year. This last option might be desired in case of a major change in the infrastructure network in a specific year.

Accessibility is the main ‘product’ of a transport system. It determines the location advantage relative to all other locations. The transport model generates a number of utility-based accessibility measures. The utility-based accessibility measures for GUM land-use are derived from the Central Leicestershire Transport Model (Petersen et al., 2006). The CLTM is a discrete choice type of transport model based on micro economic utility theory. With such a model it is possible to generate the logsum value, an aggregate value expressing the utility of diverse alternatives. Well-known references for such type of models and the logsum variable are McFadden (1981), Ben-Akiva and Lerman (1985) and Daly and Zachary (1976).

The CLTM produces person type and purpose specific logsums for the housing market sub model. These logsums express the utility of different modes, destinations and time-of-day options. In formula:

\[
L_{m,p,o} = \ln \sum_j e^{V_{m,p,o,j}}
\]

where \(L_{m,p,o}\) is the logsum of purpose \(m\), person type \(p\) in origin zone \(o\), \(V\) is the systematic part of the utility by purpose \(m\), person type \(p\), origin zone \(o\) and combination of mode and destination zone \(j\).

Residential location choice decision are made at a household level and therefore, the person type specific logsum indicators, need to be transformed into household type specific logsum indicators. Furthermore a logsum indicator including all purposes is needed. The following formula has been applied:

\[
L_{h,o} = \sum_{m,p} f_{m,p,h,o} L_{m,p,o}
\]

where \(L_{h,z}\) is the logsum for household type \(h\) in origin zone \(o\), \(L_{m,p,o}\) is the logsum of purpose \(m\), person type \(p\) in origin zone \(o\) and \(f_{m,p,h,o}\) is average number of tours for purpose \(m\), person type \(p\), household type \(h\) and origin zone \(o\). All logsum values are for an average working day. The fractions of person types by household type are available in the CLTM transport model and they have been derived from the National Travel Survey (NTS).

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Similar “logsum” accessibility measures have been generated as explanatory variables for the labour market module. These variables address the accessibility of a firm for its employees and the accessibility of other economic activities for trips departing from a firm (business purpose).

The performance of the transport system also affects the size of the housing market. The market size varies with changes in the transport system and a travel time indicator is included in the residential location choice module to model the impedance between the old and new location.
4. APPLICATION TO LEICESTERSHIRE

4.2 Geographical scale levels

The GUM model applies three geographical scale levels: the study area, regions and zones. Figure 3 visualizes the regions and zones that are distinguished within the Leicestershire study area.

Legend

- CLTM zones
- LA districts

In the GUM project the study area covers Leicestershire; the model simulates land-use developments within the boundaries of the study area. Scenario-based developments are included in the simulation as exogenous input at study area level. The demand side of the labour market is modelled at regional level. In the GUM project, regions are specified as counties and unitary authorities. Within Leicestershire eight regions are distinguished, including Leicester UA. Next at the zonal level all other distributive effects are simulated, such as employment growth, demographic development and migration. The GUM land use model comprises of 467 zones within the study area.
area, that correspond to the zones in the Central Leicester Transport Model (CLTM).

4.2 Application data

The GUM land use model uses a number of data from for the Leicestershire case study. Most of this data was available through the Office of National Statistics (ONS), the Office of Deputy Prime Minister (ODPM) or the National Trip End Model (NTEM). Table 1 gives an overview of the origin of the various variables in the land use model.

Table 1: Overview of data sources for the GUM land use model

<table>
<thead>
<tr>
<th>Module</th>
<th>Target variable / event</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demography</td>
<td>Population: in 1 year age groups and to gender</td>
<td>Census '01 (ONS)</td>
</tr>
<tr>
<td></td>
<td>Households: number, to types?</td>
<td>Census '01 (ONS)</td>
</tr>
<tr>
<td></td>
<td>Birth/mortality rates</td>
<td>Key Population and Vital Statistics (ONS)</td>
</tr>
<tr>
<td></td>
<td>In- and Out-migration: specified to age groups (4)</td>
<td>Key Population and Vital Statistics (ONS)</td>
</tr>
<tr>
<td></td>
<td>Population forecasts</td>
<td>TEMPRO (NTEM)</td>
</tr>
<tr>
<td>Housing market</td>
<td>Housing units</td>
<td>Census '01 (ONS)</td>
</tr>
<tr>
<td>Labour market</td>
<td>Workplaces</td>
<td>Census '01 (ONS)</td>
</tr>
<tr>
<td></td>
<td>Employment by industry category</td>
<td>IDBR: number of firms by size OR by industry (Ward)</td>
</tr>
<tr>
<td></td>
<td>Workforce: to gender, age and FT/PT work</td>
<td>Census '01 (ONS)</td>
</tr>
<tr>
<td></td>
<td>Employment forecasts</td>
<td>TEMPRO (NTEM)</td>
</tr>
<tr>
<td>Land use and real estate</td>
<td>Industrial real estate supply</td>
<td>Commercial and Industrial Floorspace statistics (ODPM)</td>
</tr>
<tr>
<td></td>
<td>Agricultural and urban land use</td>
<td>Agricultural Land Classification (Multi-Agency Geographic Information for the Countryside)</td>
</tr>
<tr>
<td></td>
<td>Planning data: Residential units and proposed employment sites</td>
<td>Halcrow &amp; planning authorities</td>
</tr>
</tbody>
</table>
4.3 Model estimation/calibration

Besides databases to apply the model, coefficients are needed to represent the location choice behaviour of different household segments and firms (jobs). Model calibration or estimation procedures differ widely between LUTI models and specific applications. A major distinction can be made between the equilibrium type of models, normally calibrated on the base year, and incremental models calibrated on the changes over time. Another differentiation can be made between a formal statistical and informal calibration procedure. The coefficients in most LUTI models, up to our knowledge, are calibrated informally by matching model results with observed data sets or by using expert judgment values for the coefficients. These procedures do not indicate in formal statistical parameters whether coefficients are significant or not and whether model A is better than model B.

Preferable a formal statistical procedure is used, for example, a least square or maximum likelihood estimation. A statistical estimation of the model coefficients is especially important for a more realistic representation of the influence of transport on land-use. As transport is not the most dominant factor in explaining the distribution of residents or firms; an informal procedure leaves then too much space for interpretation of the parameter value by the model designer. Therefore a more objective, empirically founded, method is required to ensure a realistic representation of the influence of transport on the spatial distribution of residents and firms.

In principle the location choice parameters in the GUM model can be estimated with formal statistical procedures, as has been done with the Dutch TIGRIS XL model (Zondag and Pieters, 2005). However, the estimation of local parameters for the Leicestershire case study was outside the scope of the project. Instead, location coefficients are taken from estimations on extensive Dutch datasets. It is obvious that the spatial attributes in Leicestershire have a different range compared to the attributes in the Dutch context. In order to ensure an elasticity to the value of the spatial attributes, the GUM spatial attributes are rescaled to the Dutch context, based on the mean and standard deviation of the associated attributes, similar to standardisation. Analysis of historical developments in the Leicestershire area can help to tailor the coefficients.

4.4 Implementing land use scenarios

With various types of scenario settings different forms of spatial policies can be implemented. The land market module processes and/or predicts changes in land use and the development of new residential and industrial locations. In doing so, it takes account of previous land use developments, market demand, the level of market regulation and development plans by the government. It can range from a very regulated land-use planning system to a market driven, free real estate market. The dimensions for defining distinctive land use scenarios follow from the functional design of the land use and real estate module in Figure 4.
In summary the following dimensions for distinctive land use scenario are available:

- policy objectives in the form of a fixed total housing production for the study area;
- policy plans at zone level in the form of development plans for residential and non-residential locations. Plans are formulated regarding the amount of land designated as new residential or non-residential areas with an associated building density. This density is specific to the urban environment. Next, the demolition of houses is specified with zone specific demolition rates;
- restrictive policy objectives, such as green belt scenarios. Non-urban areas that might be attractive for urban development can be excluded from future urban development by applying restrictions to the area. Ideally, the restricted and unrestricted areas would be derived from GIS overlays with land use maps and maps with preservation areas;
- level of government influence on land use development. The degree of government interference in the spatial development in the study area can be varied with four different market settings in the land use and real estate module. The market settings can be specified distinctively for each year.

Market demand is derived from the output of the housing market module in the form of a demand/supply ratio. Policy development scenarios include a variety of measures: a housing production for the whole research area, development plans for residential and non-residential locations, demolition rates and the amount of available and restricted land use.
The land use and real estate module can be executed with different market settings. The market settings represent the level of regulation by the government. It varies from a total planned development to a total free market in which housing construction follows demand. The market settings that can be implemented:

1. Planned development:
   the only land use developments that take place are the exogenous plans. Plans include new residential or non-residential areas at zonal level with an associated building density. This market setting can be seen as a ‘controlled setting’

2. Flexible development:
   land use changes are based on developments plans by the government but these are adjusted to market demand. In case the government has unrealistic planning scenarios, the plans are downscaled if very little market demand exists for such a development. Vice versa, extra developments are executed if a large demand exists for specific plans. In this setting, market demand is derived from the MIGRAT module. This market setting can be seen as a ‘realistic setting’

3. Restricted market:
   land use changes are based on housing demand, but can only take place within set boundaries. In such a way designated areas can be protected against urban development. For the simulation procedure this means that the available land for urban development is reduced with the amount of restricted areas. This setting provides the opportunity to implement ‘Green Belt’ scenarios.

4. Free market:
   land use changes are based on housing demand. The search area for new urban areas is unrestricted within the available non-urban land use (usually agricultural)

4.5 Test results

The work on the GUM land use model is still ongoing. At the upcoming conference the first results of the simulation results will be presented. These simulations will be based on the data specified in Table 1 and preliminary accessibility inputs that come from the CLTM transport model.

5. CONCLUSIONS

The presented GUM land use model forecasts land-use responses to transport change. Vice versa, the results of the land use model provide consistent forecasts of the spatial distribution of residents and jobs, tailored to the needs (spatial zoning, segmentation) of the transport model. The approach is developed in an application for the Leicestershire County Council. The presented generalised approach can be used by the UK Department for
Transport to test impacts of land use and transport policies and exogenous developments on larger, non-metropolitan, urban areas throughout Great Britain.

This contribution focuses on the land use component of an integrative land use and transport model. Such a tool provides the opportunity to analyse different policy objectives. First of all effects of transport policies on the spatial distribution of jobs and residents can be analysed. Next, the impact of distinctive land use policies, e.g. localised development plans or green belt scenarios, on transport demand can be analysed as well. Currently test runs are being performed to explore the possibilities to evaluate impacts of distinctive land use policies, given the available scenario dimensions in the presented model.

Bringing together the land use and transport model within one integrated package contributes to the ex ante analysis of policy packages targeting at sustainable development. Over the last decades it has become clear that the problems of an ongoing growth of transport in urbanized regions, like congestion and environmental externalities, cannot be solved by conventional transport measures alone. There is widespread agreement that in order to bring about sustainable travel in urban areas, integrated policy packages – comprised of a cross-sectoral mix of regulatory, pricing, and technological measures among others- are needed to send the right signals to both supply and demand elements in the urban land use and transport markets (ECMT, 2002). Successful implementation of these policy packages aims to integrate land use and transport planning. The GUM package is well suited to evaluate such integrated policy packages. Particularly the explicit modelling of green field and brown field developments supports the analysis of the dominant suburbanization trend.

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