Chapter 5
Coupling a Detailed Land-Use Model and a Land-Use and Transport Interaction Model

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5.1 Introduction

As already described in the preceding chapter, the study ‘The Netherlands in the Future; The Second Sustainability Outlook’ (MNP, 2007) constructed alternative future spatial strategies for the Netherlands and evaluated them using a diverse set of sustainability indicators, such as flooding safety, biodiversity, accessibility and landscape protection. As in previous studies, Land Use Scanner was used here as an instrument to allocate demand for land of different land-use types within a region. At a regional level, this demand had been calculated earlier by sector-specific models for the Baseline scenarios. The analytical framework was further extended with the Tigris XL model, a Land Use and Transport Interaction model (Significance & Bureau Louter, 2007). The specific objectives for using the Tigris XL model in addition to Land Use Scanner were:

- To simulate transport endogenously and analyse the impacts of joint alternative spatial and transport strategies on transport indicators (such as congestion) and accessibility indicators (in both geographical and monetary terms);
- To simulate and analyse the mutual influence of land use on transport and transport on land use;
- To calculate the impacts of alternative land-use and transport strategies on the housing and labour market at a regional level.

Land Use Scanner and Tigris XL were applied for the first time together within one analytical framework in ‘The Netherlands in the Future’ project. The interaction between the models was set up within the project by following a pragmatic approach that used the strength of both models without making fundamental changes to either of them. Generally speaking Land Use Scanner provides more detail about the
supply side of land by distinguishing more land-use types and contains detailed characteristics related to location, for example spatial planning policies. Apart from the incorporation of transport, Tigris XL provides more detail to inform its demand modelling, for example by simulating choice of location by different household types and economic sectors.

However, to be able to successfully link both instruments within one analytical framework, it is important that the consistency between Land Use Scanner and Tigris XL increases in terms of classifications, spatial units, and time horizons used. To improve the consistency, input data for the two models was harmonised as far as possible. For some data categories, an adjustment of the classification is also needed. In addition to harmonizing the data, alternative ways of interaction between the two models were tested to see how the models might make best use each other’s merits.

Following this short introduction, a short description of the Tigris XL model and its characteristics is given in Section 5.2. For a description of Land Use Scanner reference is made to Chapter 1 of this book and previous papers (e.g. Hilferink and Rietveld, 1999). Section 5.3 describes how Land Use Scanner and Tigris XL have been linked. A description of an actual application of the combined framework follows in Section 5.4. In Section 5.5 conclusions are presented regarding the interaction between the two models, the contribution of the combined framework to policy-making and recommendations for further improvement of the framework.

5.2 Short Description of Tigris XL

In the period 2002–2005, a consortium of Significance (part of RAND Europe at the time) and Bureau Louter developed the Tigris XL model in a number of sequential projects for the Transport Research Centre in the Netherlands (part of the Ministry of Public Works, Transport and Water Management). These projects consisted of a combination of model development, model application and model testing. Tigris XL is a so-called Land Use and Transport Interaction (LUTI) model, which uses the National Transport Model (LMS) of the Netherlands as its transport module (RAND Europe & Bureau Louter, 2006a; Zondag, 2007).

The key characteristics of the Tigris XL model are:

- It is a dynamic land-use model simulating time steps of 1 year. This enables it to simulate path dependency and to analyse how the system evolves over time. The key reason for this approach is that, due to many different time lags in the system (economic cycles, planning cycles, construction time, etc.), a general equilibrium does not exist in land use. Within its incremental structure the model uses partial equilibrium conditions, for example to match supply and demand within a year on the housing market.

- The module for choice of residential location has been statistically estimated, for six different household types, based on a large housing market survey (over 100,000 respondents). The module for choice of location of firms (represented as jobs in the model) has been estimated at municipality level for seven economic sectors on time-series data for the period 1986–2000. This enables the model to:
estimate the relationship between location of jobs and location of residents. Tigris XL does not use a pre-assumed hierarchical relationship but rather one that, based on estimation results, varies between economic sectors and household segments;

- statistically estimate, based of revealed preference data, the influence of accessibility on the distribution of households and jobs.

- The land-use and transport system is simulated in Tigris XL in a set of linked modules addressing specific aspects of the systems (e.g. demography). The overall architecture determines the sequences of the modules and data exchanges between the modules. This allows flexibility to change or re-estimate specific modules without the need to change the whole framework.

- The land-use model operates in a way tailored to the National Transport model (LMS) of the Netherlands. The spatial detail of the land-use model is at the level of transport zones.

- The model has a three-layer structure, namely land, objects (such as dwellings) and activities (people, jobs).

- The land-market module in Tigris XL has different options to simulate the influence of government on spatial development. Depending on its settings it can simulate new urban development in three ways:
  - as a free-market development following the preferences of residents and firms. Location choices are only restricted by the lack of available land or possible spatial planning restrictions (such as nature areas);
  - as regulated development via designated locations and numbers of houses (in this case only the location choice of residents is simulated with the model); or
  - as an intermediate variant that takes development plans as a starting point but adjusts them within a certain range to actual market demand.

Tigris XL consists of five modules, which together address demography and spatial markets. Figure 5.1 presents an overview of the model and the main relationships between the modules. The model distinguishes two spatial-scale levels: the municipality level (approximately 450 regions) and local transport zones of the National Model System (LMS sub-zones; 1,308 sub-zones cover the Netherlands).

Core modules in the model are the housing market and labour market modules. These account for the effect of changes in transport on residential or firm location behaviour and in this way link changes in the transport system to changes in land use. A land and real-estate module simulates supply constraints arising from the amount of available land, land-use policies and construction. The module defines different levels of government influence on spatial development, ranging from completely regulated towards free market, and various feedback loops between demand and supply are also available. A demographic module is included to simulate demographic changes at the local level. At the national level, the model’s output is consistent with existing demographic and socio-economic forecasts for population, labour force, income levels and employment.
The demographic module addresses processes such as births, deaths and ageing of the population, as well as changes in the composition of households. It deals with persons by category (gender, age) as well as households by category (size, income, etc.). The demographic module operates at the local subzone level and also processes the spatial distribution of scenario-based international migration flows.

The land-market and real-estate market module processes changes in land use and buildings, office space and houses, and addresses both densification of houses or floor space within existing urban areas and green-field developments. The changes within the existing urban area are exogenously specified and only administrated within this module. The simulation of the land-use changes in non-urban land can be modelled exogenously or endogenously depending on the setting for the level of market regulation. As said before, this can vary from a regulated land-use planning system, using exogenous input on the size and location of development sites, to a non-regulated market endogenously calculating the size and location of development sites.

The aim of the housing market module is to simulate annual moving (if any) of households. The housing market module simulates two choices: the choice to move or stay, and the choice of residential location following a move. The choice of residential location has a nested logit structure and incorporates a regional and a local scale level: there is a choice of region and a choice of location within the region. Choices depend on household characteristics, local amenities, prices, accessibility and distance (travel time) between the new and old residence. The parameters of the move/stay and residential location choice function, for each
household type, have been estimated from a large four-annual housing market survey of more than 100,000 households in the Netherlands.

The labour market module in Tigris XL models changes in number of jobs by seven economic sectors and changes in workforce at a regional and zone level. For each sector, the influence of accessibility on the spatial distribution of employment has been modelled in combination with a set of other explanatory variables. The parameters have been estimated on a historical data set (1986–2000) including employment figures by sector at a municipality level. The labour market module interacts with the demographic, land and real-estate, housing market and transport modules.

The transport module calculates changes in transport demand and accessibility and is integrated with the National Transport Model (LMS). The LMS consists of a set of discrete-choice models for various choices in transport such as round trip frequency, mode of travel and destination, departure time and route. The LMS is based on micro-economic utility theory, enabling the derivation of utility-based accessibility measures.

Since its finalisation, Tigris XL has been used to evaluate a variety of transport and spatial policies. Examples of the application of the model for evaluating policy issues include the evaluation of a new road or rail infrastructure, transport pricing policies, land-use plans and urbanisation strategies (RAND Europe & Bureau Louter, 2006b; Significance & Bureau Louter, 2007, 2009; Significance et al., 2007).

The model has been applied for the evaluation of the following issues:

- Effects of long-term socio-economic scenarios on transport and land use, including the translation of socio-economic trends and land-use plans into socio-economic input data for the transport model;
- Land-use effects of transport policies, including road and public transport infrastructure and operations, as well as pricing policies;
- Effects of alternative land-use policies on land use and transport:
  - for new residential or commercial development sites, the model can use different assumptions for the regulation of the land market;
  - urban densification strategies;
- Effects on land-use and transport of integrated land-use and transport strategies.

### 5.3 Linking Tigris XL and Land Use Scanner

This section describes how the coupling between Tigris XL and Land Use Scanner has been set-up. It discusses which information is exchanged, the conversion and/or processing steps and what modifications have been made to the Tigris XL model. First a brief overview is presented of the main differences and overlaps between the two models. This overview was needed to design the proper level of interaction between the models.
5.3.1 Overview of Differences and Overlaps

When Tigris XL and Land Use Scanner are compared it can be concluded that:

- Both models have different allocation mechanisms. In Land Use Scanner, regional claims for housing, labour, etc., are allocated to grid cells by a constrained logit model specifying the highest utility. The allocation is constrained by land-use claims provided at the regional level. The Tigris XL model allocates national projections to the regional and zone level by simulating the demand preferences of residents and firms. In both models, supply-side restrictions, depending on land characteristics and spatial planning, influence the location choices. This occurs in Tigris XL at the zone level and in Land Use Scanner at the grid cell level.

- Land Use Scanner uses exogenous land claims at a regional level as input and land use by grid cell (100 m × 100 m) as its output. This means that the model simulates only changes in land use within regions and not processes leading to land-use changes in other regions (e.g. overflow effects from large cities to adjacent regions). Tigris XL uses national demographic and economic scenario projections as input and simulates both the inter-regional and intra-regional changes in population, employment and land use.

- The Tigris XL model simulates land-use changes resulting from urban development or government plans but does not simulate changes between different types of non-urban land-use functions. Land Use Scanner simulates changes in urban and several non-urban land-use functions, including agriculture and nature. The model also simulates non-urban transitions in land use.

- A nation-wide classification system exists to classify residential areas in the Netherlands by type of neighbourhood, for example, countryside or urban centre. In Tigris XL, the classification of residential area types is a fixed exogenous input per zone. Land Use Scanner calculates endogenously changes in residential area types for the cells (e.g. from non-central into central urban area). This means that in future years Land Use Scanner will classify the grids (and indirectly the zones they are located in) differently from Tigris XL (which uses percentage of residential area types at zone level).

The key characteristics of the two models are summarised in Table 5.1.

5.3.2 Set-Up of Interaction

For the ‘Second Sustainability Outlook on the future of the Netherlands’ project (MNP, 2007) Tigris XL and Land Use Scanner were loosely coupled (see Fig. 5.2). In this set-up the models operate individually and interactions between the models take place by exchanging input and output through data files. By setting up these interactions, some modifications have been made to Tigris XL to take advantage of data available in Land Use Scanner and to improve the consistency in data.
Table 5.1  Key characteristics of land use scanner and Tigris XL at various spatial and temporal resolutions

<table>
<thead>
<tr>
<th>Spatial and temporal resolution</th>
<th>Land use scanner</th>
<th>Tigris XL</th>
</tr>
</thead>
<tbody>
<tr>
<td>National level</td>
<td>Uses scenario input directly in definition of local suitability and indirectly as input for the sector models calculating the regional claims</td>
<td>Uses scenario input</td>
</tr>
<tr>
<td>Regional level (e.g. 12 provinces, 40 COROP regions or over 400 municipalities)</td>
<td>Exogenous input of land claims for employment, housing and other sectors can be provided at any regional level</td>
<td>Provides an initial spatial distribution of residents and employment at level of municipalities</td>
</tr>
<tr>
<td>Zonal level (1,308 LMS sub-zones for the Netherlands)</td>
<td>Not applicable</td>
<td>Simulates spatial distribution of residents and employment, land-use change and changes in accessibility</td>
</tr>
<tr>
<td>Local level (100 m × 100 m grid cells)</td>
<td>Simulates land-use change for the cells using the regional claims and local (multi-criteria) suitability definition</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Transport network</td>
<td>Static accessibility indicators are used to describe local suitability, no dynamic network is included</td>
<td>Calculates transport indicators such as travel times, number of vehicles and congestion</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>2010, 2020, 2040</td>
<td>Yearly until 2040</td>
</tr>
</tbody>
</table>

Fig. 5.2 Interaction between Land Use Scanner and Tigris XL (TXL)

classes between the models. In addition, post-processing procedures have been developed to transform Tigris XL output such as residents, houses and employment by sector into regional land-use claims, which are used as input data for Land Use Scanner.
The manner in which Land Use Scanner and Tigris XL are coupled depends on which type of housing market is assumed in the particular application. The housing market in the simulation can either be a regulated market, with fully planned development of all new housing construction, versus a more free market, consisting, for example, of a zoning policy and market-driven construction of houses. In the first case, the location or zone of green-field housing construction on agricultural land is determined exogenously in Tigris XL. Output of Land Use Scanner for 2020 and 2040 related to new residential areas is used as input data (in terms of hectares and number of houses) for Tigris XL. Land Use Scanner output data is processed by aggregating the cell data to the zone level and by distributing the simulated developments into time steps of 1 year. In the second case, the demand preferences of households, as simulated in the module for choice of residential location in the Tigris XL model, influence the location of housing construction. The resulting population developments also influence the location of new economic activities, which is calculated in the labour market module of Tigris XL. Both the residential and employment developments are then converted into land claims at the regional level and used as input for Land Use Scanner. Both types of coupling are discussed in more detail in Section 5.3.4.

5.3.3 Use of Land-Use Data and Restriction Maps

Several changes were made to the land-use classification and data of Tigris XL to improve consistency with Land Use Scanner and to take advantage of the detailed land-use information in the latter. The following changes were made:

- The land-use category of housing in Tigris XL was split into three residential area types similar to those used in Land Use Scanner. At the housing stock level in Tigris XL, a classification of five residential area types is used, which can be simply aggregated into the three categories of Land Use Scanner.
- The land-use type of agriculture in Tigris XL was split into agriculture and horticulture, based on data from Land Use Scanner. The two categories needed to be distinguished to reflect differences in the cost of acquiring land for urban development.
- Maps restricting the options for development in Land Use Scanner, for example those related to external safety, noise pollution, nature protection and hydrological constraints, were used in Tigris XL to exclude locations as options for development.

5.3.4 Interactions for Differing Housing Market Circumstances

This subsection describes in more detail two alternatives ways in which Land Use Scanner and Tigris XL have been linked. The preferred way of coupling the two systems depends upon assumptions made about housing market conditions. If the
housing market is more regulated and thus supply-driven then the detailed supply information from Land Use Scanner plays a more dominant role, but if the housing market is more demand-driven then the demand modelling in Tigris XL plays a more dominant role. It is assumed that the location choices of firms will not be strongly regulated and in both of these Land Use Scanner–Tigris XL coupling options, the labour market module in Tigris XL has been used to calculate the spatial distribution of employment.

In cases of regulated or planned housing supply, the supply information on new residential locations as simulated per grid cell in Land Use Scanner for 2020 and 2040 are exported to fill the planning files of Tigris XL by year, zone and residential area type. The housing market module in Tigris XL uses houses as supply unit instead of hectares of residential land and the number of newly constructed houses by zone are calculated based upon the hectares of new residential construction by type (e.g. central urban area, green urban area, countryside etc.) and region-specific density figures by type (ABF, 2006). Because Land Use Scanner simulates changes in residential land use and not in houses, the model is better fitted to simulate urban expansion than urban restructuring. For that reason, in the Second Sustainability Outlook study, housing construction in currently built-up areas was subtracted from the total regional housing construction target that was underlying the regional land claims for housing. In Tigris XL the number of houses to be constructed in currently built-up areas is contained in a separate input file at the zone level. Then, this number of houses in currently built-up areas is made consistent with the total regional housing targets, minus the housing developments realised at the new residential locations. In the scenarios, the share of brown field and green field developments differs depending on the strategy chosen for urban development.

Both the housing construction within and outside existing built-up areas is input for the housing market module in Tigris XL. The newly constructed houses are included as vacant houses by zone for the supply side of the module for choice of residential location. This module simulates the housing moves and location choices of the households. The module for choice of residential location and the demographic module together calculate for each year the changes in population (by age and gender) and households (by size and income class).

The labour market module in Tigris XL calculates the spatial distribution of employment for seven economic sectors, in the first step at a municipality level and in a second step at the level of the zones. The results (statistical regressions) of this module show that overall the spatial distribution of people influences the location choices of firms, although the existence and strength of this relationship differs strongly by economic sector (RAND Europe & Bureau Louter, 2006a). The changes in employment by sector, calculated by Tigris XL, are used as input for a post-processing step to calculate the regional claims for commercial and industrial land. This post-processing module was developed by Bureau Louter and for a description reference is made to Significance and Bureau Louter (2007). This step uses, besides the calculated changes in employment, information on location preferences of the sectors (e.g. for commercial sites), assumptions on the changes in these preferences in the future, and developments in average land use per
employee per sector. These factors together determine the future land-use claims for commercial and industrial sites, public facilities and airports and sea ports. These land-use claims are calculated for the years 2020 and 2040 at a regional level, which is needed as input for Land Use Scanner.

In cases where housing supply is market (demand) driven, an alternative housing construction module is used in Tigris XL in which the housing construction rates at the level of zones are based on the location preferences of the household and the availability of land. To take better advantage of the detailed supply information in Land Use Scanner, the housing construction module in Tigris XL has been modified to be used in the integrated framework. In the new set-up, the main differences with the other approach are that demand surplus is now calculated specifically for each of the three residential area types and aggregated to the municipality level. Information on the highest suitability scores by residential area type in Land Use Scanner was used at the zone level to allocate housing construction within the municipality to the zones (see Fig. 5.3).

Under both market conditions, the Tigris XL model is used to generate the land-use claims for employment. The labour market module in Tigris XL calculates the changes in employment and a post-processing procedure module is used to convert these changes in employment into land-use claims for commercial and industrial land.

Land-use claims (in hectares) computed using output from Tigris XL at the COROP regional level were used as input for Land Use Scanner. Projected Tigris XL

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Fig. 5.3 Flow diagram of the adjusted housing construction module in Tigris XL (TXL)
demands for housing and employment by economic sector at LMS zone level were translated into land-use claims and subsequently used as input for the alternative land-use scenarios.

5.4 A Policy Application of the Combined Framework

The Land Use Scanner–Tigris XL framework was used in the Second Sustainability Outlook study to calculate the land-use and sustainability impacts of alternative scenarios and variants (MNP, 2007). The scenarios consisted of alternative future spatial and transport strategies for the Netherlands. One of the alternative land-use scenarios, the Uplands variant, is described here to illustrate the functioning of the combined framework.

The Uplands scenario entails a radical break with past trends in spatial development in the Netherlands. Under the scenario, new housing and employment areas, in the period from 2010 to 2040, are relocated from the low-lying, highly urbanised western part of the Netherlands (the Randstad area) to more peripheral areas lying above sea level and outside flood-prone areas near rivers. The Uplands scenario was developed to represent an extreme climate adaptation scenario. With current knowledge on the effects of climate change, the Netherlands is expected to be ‘climate-proof’ and protected from rising sea levels for some centuries to come. Structural spatial measures, such as a shift in investment to the upland areas of the Netherlands, are thus not urgently required. Yet, these were included in this scenario to show the potential implications of such drastic measures that are regularly suggested in adaptation studies.

To simulate the Uplands scenario, the housing construction module (see Fig. 5.3) used input data from both Tigris XL and Land Use Scanner. This scenario results in a markedly different land-use development compared to the Baseline scenario, which follows as much as possible current plans. Table 5.2 shows the differences in population development between the two scenarios; the country is divided into three parts - the urban core (Randstad), a surrounding intermediate area and the periphery in the far North, East and South of the country. The table shows that the strategy underlying the Uplands scenario results mainly in a shift in population from the urban core towards the higher, intermediate area. The periphery is also mainly located above sea level but this area does not attract many additional residents due

<table>
<thead>
<tr>
<th>Part of the Netherlands</th>
<th>Population baseline scenario</th>
<th>Difference Uplands variant minus baseline scenario</th>
<th>Percentage population change in 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Randstad</td>
<td>7,826,331</td>
<td>-872,141</td>
<td>-11%</td>
</tr>
<tr>
<td>Intermediate zone</td>
<td>5,005,661</td>
<td>775,355</td>
<td>15%</td>
</tr>
<tr>
<td>Periphery</td>
<td>4,306,562</td>
<td>97,091</td>
<td>2%</td>
</tr>
</tbody>
</table>
to its relative poor accessibility to employment and services as compared to the Baseline scenario.

Figure 5.4 shows the population developments for the Uplands variant in the period 2010–2040 by region. The map shows clearly that the population in the area below sea level declines as a result of the assumed construction stop in combination with a falling average household size. Population growth takes place mainly in the regions above sea level and those bordering the urban core. Especially the province of Brabant, in the south of the country, can expect to experience high population growth. Areas in the middle of the Netherlands, where the river Rhine crosses the country from Germany to the North Sea, can expect lower population growth because the underlying strategy limits building options in this area due to increased risk of flooding. Although population development in the periphery is somewhat higher in the Uplands scenario than the Baseline scenario (see Table 5.2), there are regions in the periphery that nevertheless can expect a decline in population in the period 2010–2040.

Unlike residential developments, labour market developments are not restricted in the Uplands scenario. This assumption reflects Dutch planning practice, in which the construction of new houses is historically strongly regulated, while the location of employment is far less regulated due to oversupply of commercial real estate and competition between different regions. The large population shift from the Randstad to the intermediate zone is also reflected in the spatial growth pattern for employment, as presented in Fig. 5.5. The labour market module simulates
seven economic sectors and employment in most of these sectors, as consumer services or government, is influenced by population developments. Other sectors, such as commercial services, that respond to changes in employment are indirectly influenced by the population through changes in the employment resulting from the population following economic sectors.

Figure 5.6 presents the high-resolution land-use projections for the Uplands Scenario from Land Use Scanner, taking the population and employment developments at the COROP level from Tigris XL.

The integration of Land Use Scanner and Tigris XL makes it possible to calculate transport impacts and to include the mutual influences of changes in land use on transport, and vice versa. Different accessibility indicators were calculated referring to different definitions of accessibility. The congestion indicators show that the shift in population growth from the urban core to the intermediate area results in overall lower losses in traffic congestion time in 2040. Of course this pattern is regionally diverse, with a decline in congestion in the urban core and a strong increase in the intermediate zone. Applying a geographical accessibility indicator, representing the number of jobs that can be reached by car (during off-peak and peak hours) and public transport, shows a decline in the number of jobs that can be reached for the Uplands scenario as compared to the Baseline scenario.

As mentioned above, the Tigris XL model incorporates the LMS transport model of the Netherlands as its transport module. The LMS is a discrete choice type of transport model, which makes it possible to calculate the monetary accessibility
impacts following the logsum method (see Geurs, Zondag, De Jong & De Bok, 2010). The logsum method calculates, at a disaggregate level of person types, the differences in utility between a policy variant and a reference scenario. The cost coefficients in the utility functions can be used to convert the changes in utility into monetary terms. The advantage of the logsum method is that it can calculate the accessibility benefits of both transport and spatial strategies, while traditional measures only address the benefit of transport policies. The Uplands scenario does not assume any changes in the transport system and all accessibility benefits result from changes in the spatial planning strategy. Compared to the Baseline scenario, the Uplands variant would bring with it a high loss in accessibility totalling −521 million euros a year in 2020 (expressed in 2005 euros) and −1,182 million euros in 2040.
5.5 Conclusions and Directions for Further Research

This chapter describes the combined use of the Land Use Scanner and Tigris XL models within the same framework for the Second Sustainability Outlook study. The interaction between the models was set up pragmatically without making fundamental changes to either of the models. The combined modelling framework was used to analyse the impacts of alternative integrated spatial and transport strategies. Combining the modelling framework has a number of advantages:

- Detailed land-use data and plans from Land Use Scanner improve the simulation results of the residential location choices within Tigris XL and, thus, indirectly improve the simulation of the spatial distribution of employment (as these sectors influence each other).
- Conversely, Tigris XL simulation results for employment at a regional level, and associated changes in land use, can be used as land-use claims for Land Use Scanner in a feedback interaction. The Tigris XL model ensures consistency between population and labour developments.
- The combined Tigris XL and Land Use Scanner framework facilitates the analysis of the impacts of integrated land-use and transport policies. The results include impacts of changes in the transport system on the spatial distribution of residents/firms and land use and, conversely, the influence of changes in land use (and spatial distribution of residents and firms) on the transport system. Within Tigris XL, these mutual impacts can be analysed at the level of transport zones (1308 zones for the Netherlands); within the combined framework these effects are exchanged between Tigris XL and Land Use Scanner at the regional level. Land Use Scanner further allocates these changes to the grid cell level.

The inclusion of Tigris XL in the combined framework, and in so doing also the national transport model, enables the calculation of additional indicators, such as:

- Transport indicators for the alternative spatial and transport strategies, for example mode split and congestion effects.
- Accessibility impacts, expressed in geographical accessibility indicators as well as in the monetary benefits of changes in accessibility. The option to calculate the monetary benefits of changes in accessibility, due to transport policies as well as land-use policies, played an especially important role in the evaluation of alternative transport and spatial strategies. The results of the calculation showed that spatial strategies had large monetary accessibility benefits. This is, for example, illustrated by the much higher accessibility benefits of an urban density strategy, which was also considered in the sustainability outlook, in comparison with a large road-infrastructure investment programme (see Geurs et al., 2010).

The combined application of Land Use Scanner and Tigris XL was considered as promising and the framework has made a substantial contribution to the ex-ante evaluation of various policies, as discussed above. However, the interaction between
the instruments was established only in a practical manner and a more fundamental integration of the instruments, or their respective knowledge, is still needed to further reduce overlaps and inconsistencies between the two and to fill in missing aspects.

A general observation is that simulations of the use of land (such as agriculture or residential), objects (such as houses or offices) and actors (such as people or firms) are closely related. Therefore an important direction for further research is to develop a more integrated and consistent approach towards modelling these three layers in time and space. It is clear that there are still many inconsistencies and omissions in the current combined framework when spatial changes in the number and distribution of residents, jobs, houses and in land use are calculated: inconsistencies and omissions between the three layers, between different spatial scale levels, and in time. To address these matters, we recommend several fundamental improvements of the framework:

- **Explicit modelling of objects and actors at a lower geographical level in integration with land-use changes.** Currently regional land-use claims derived from regional changes in population, housing or employment are allocated to the grid cell level. This often requires a post-processing step to transfer land use at the grid cell level into, for example, the number of people or firms. Information on the number of people or firms at the grid cell level is needed to be able to calculate indicators such as flood damage or environmental pollution. Explicit modelling of actors and objects within the region also enables improvements in the modelling of regional markets (e.g. housing and labour markets) and the behaviour of actors in these markets;

- **Use of one or more consistent theories throughout the analytical framework.** The use of a sequential set of models as described in this chapter, results in applying different theoretical principles at different spatial levels of scale. For example, different approaches are used for the simulation of choices of residential location within a region and for choices between regions. Although the underlying processes can be different at a regional and local level, for instance, more job-related migration at a regional level versus more housing-condition related moves at a local level, the use of a consistent approach (e.g. utility theory) would help to interpret modelling results in a consistent way in the policy evaluation.

- **Improve the inclusion of supply information, such as land-use restrictions and options, in the modelling of regional developments.** Ideally, this would mean that existing boundaries are less strictly enforced to allow conditions within a region to have an influence on interregional developments through feedback mechanisms (e.g. additional land-use restrictions in the Amsterdam region impact on the number of people in the nearby municipality of Almere). A first step has been made in this direction but additional steps are needed to improve the inclusion of land in the specification of the sector models.

- **Harmonise the temporal resolution of the model components.** TIGRIS XL is an incremental model that uses time steps of 1 year, while Land Use Scanner is
an equilibrium model that is normally applied for time horizons of 10, 20 or 30 years. Preferably, the interactions or data exchanges would take place annually to allow for path dependency and analysis of the developments over time.

References


