Simulating urban dynamics through integration of socio-economic and land-use models

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The notion that economic and land use change processes interact, is common knowledge. How to simulate this interaction in (integrated) models is not that straightforward. Both disciplines have co-existed for decennia and each has developed its own concepts and (modelling) paradigms. When integrating models from these different disciplines, underlying assumptions and limitations of the existing individual models are passed on to the integrated model. A proper integration therefore requires a thorough understanding of the underlying theories of both types of models. Over the past decade, several attempts have been made to integrate socio-economic models with land-use change models. In most cases, however, there is a uni-directional relation from the socio-economic model(s) to the land use change (LUC) model by providing land use demands based on demographic and economic developments.

This presentation presents an integrated spatial decision support system (ISDSS) for simulating urban and regional dynamics, for which prototypes (developed in the first four years of a six year programme) have been applied to the Auckland and Wellington regions in New Zealand (Figure 1). The aim of this ISDSS is to support long-term integrated policy development and planning by taking into account social, cultural, environmental and economic developments. An important aim of the approach is to show the trade-offs that need to be made when deciding about future development directions and therefore simulating the impact of alternative scenarios on the economy as well as the environment was found crucial.

The ISDSS has a temporal resolution of one year and a time horizon of 40-50 years into the future. The spatial resolution is 100 m and its extent is the size of the districts that together make up the metropolitan area and its outskirts; in both cases an area of roughly 150 x 150 km. The ISDSS includes three components: an ecological economic model, a demographic model and a land use model. *Macro-economic processes* are represented using the Region Dynamic Economy Environment Model (RDEEM) input-output model. Input-output (IO) models provide a snapshot of the structural interdependencies between industries, primary inputs and final demands for a given financial year within an economy and as such do not include a temporal component. For different years different IO tables can be constructed. Due to the inclusion of interdependencies between industries, IO models capture not only direct, but also indirect (through supply chain purchases) and induced (through

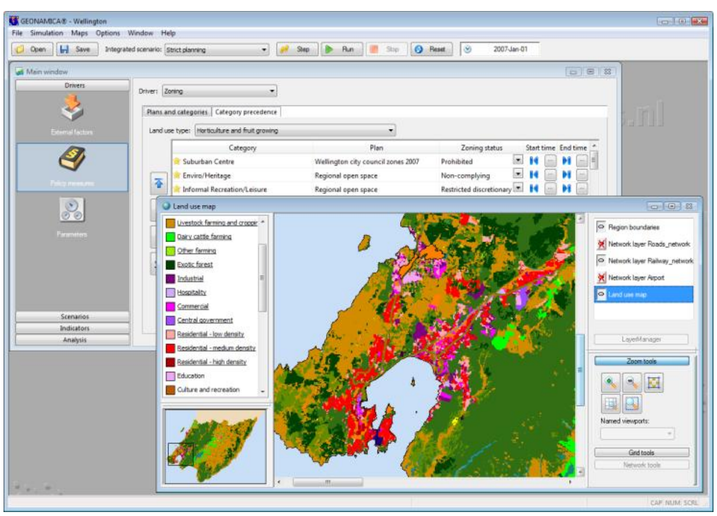

Figure 1: Screenshot of the ISDSS presenting the main window and the land use map of Wellington.

consumer spending) impacts associated with economic change. The *demographic model* used in the ISDSS is an age-cohort model that calculates population projections for the entire modelled region according to birth, mortality and migration figures. Each year of the simulation, it calculates how many man and woman are present in each one-year age cohort and by doing so an age pyramid can be created for the entire population of the region. *Changes in land use* are simulated with the Activity Based Metronamica model. This model simulates the competition for space at local level and hence the spatial allocation. It is an extension of the traditional cellular automaton (CA) based Metronamicaas it includes population and jobs at cellular level in addition to land use classes. CA-based land use models generate an organized but unpredictable behaviour of the land use system. This behaviour is represented by a large set of simple equations or rules that together create a complex behaviour that includes non-linear dynamics and emergent properties. They are simulation models that start with a land use map of the initial year and use a set of drivers (behavioural, institutional and physical) to calculate future developments.

The integration between the economic model and the land use change (LUC) model is presented in Figure 2. The macro-economic model (shown in the figure by both its demand and supply side) is an important driver for land use change in providing land use demand for a range of economic activities such as industry, commercial activities, dairying, cropping, and beef & sheep farming. The LUC model subsequently tries to allocate these demands at the local level. Only suitable and available locations are taken into account during the allocation. This avoids e.g. allocation of dairying land and industrial locations on steep slopes or urban development in conservation areas. When not all demands can be met, the competition for space between different actors is simulated by the land use allocation algorithm, and the final allocation is fed back to the economic model. The supply side of the economy is affected by this information and hence economic growth is less than what would be expected by a purely demand-driven approach. Because the IO approach captures the interdependencies between industries, the availability of suitable land can restrict growth for different economic sectors.

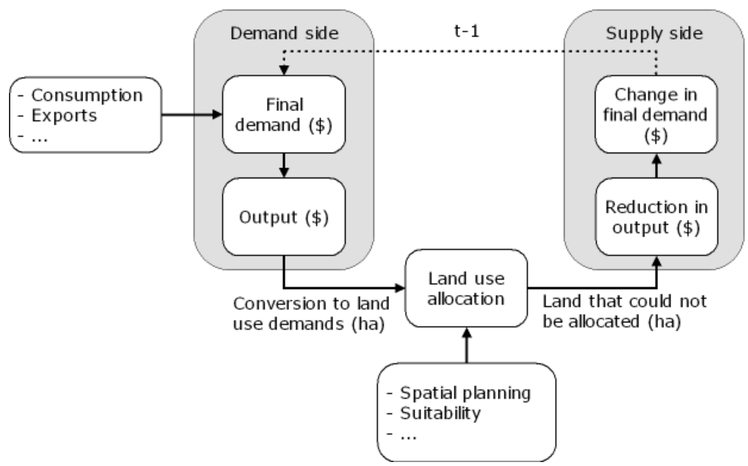

Figure 2: Schematic representation of the integration between the economic model and the land use change model.

The ISDSS demonstrates that a dynamic coupling between socio-economic and land use change models is able to simulate the feedback between both processes. Results of a applications for Wellington and Auckland show realistic behaviour of all model components. Because the integrated model is provided as an ISDSS that allows entering various policy options, calculating their impact on both the environment and the economy, and elucidating trade-offs, the system has a high potential to support policy analysis and impact assessment.

The chosen approach brings conceptual strengths and weaknesses associated with the incorporation and integration of the economic, demographic and land use models. The key strength of this approach is the integration of available resources in the supply side of the economic model, simulating how physical and institutional restrictions on land resources are limiting the land supply and hence economic growth. This offers a unique way of creating a feedback not only from the economy on the land use, but also from the land resources on the economy. Furthermore, this approach has the ability to capture the interdependencies between industries, and in turn, changes in land use requirements across all industries.

A drawback of the IO model is that this is a linear model and interdependence between industries is assumed to be constant with no technological change. This makes the model less suitable for more creative and long-term scenarios. Furthermore, when implementing the interactions between the land use and economic components a main difficulty was experienced. For the macro-economic model to operate correctly, the demand and supply side should be in equilibrium for a single year. Because the demand side impacts on the LUC model and the supply side is affected by the LUC model, equilibrium could only be obtained through an iterative procedure between the LUC and the economic component, which would have to be carried out during each time step. Such a procedure would however not match the simulation approach of the LUC model in which action and reaction are modelled over time. After reviewing several alternatives and investigating their results, it was decided to divide the demand and supply calculations over two time steps. This solution is conceptually not ideal (nor is the other solution of iterating between the economic model and the LUC model in the same time step), but was favoured because of its fit with the overall dynamic nature of the integrated model, which is related to its ability to support scenario studies and theshorter execution time (which was important for the use value of the ISDSS).

A key challenge in model integration lies in integrating models that have been developed in different disciplines. Our experience is that the equilibrium approach of economic models often poses conceptual conflicts with the simulation approach of dynamic land use change models. While sometimes the integration seems to be there when we provide both types of models in an integrated model, special care is required regarding the conceptual validity of this integration. Being able to couple models technically doesn't mean the coupling makes sense! For future research we therefore recommended to focus first on the integration of the processes and next on the model implementation.