Chapter 2
A Use-Driven Approach to Large-Scale Urban Modelling and Planning Support

Brian Deal and Varkki Pallathucheril

2.1 Introduction

Urban system simulation models are used to forecast and evaluate land-use change over space and time. Such simulation models offer planners and stakeholders an ability to view and assess the future outcomes of future policy alternatives before final decisions are made about implementation. This technology also offers the ability to improve our fundamental understanding of land-use transformation dynamics and the complex interplay between urban change and sustainable systems (Brail 2001; Deal 2001).

The literature on Planning Support Systems (PSS), and the large-scale urban modelling and simulation tools on which those systems are built, has largely focused on technical issues and system mechanics, especially the theoretical underpinnings, software architecture and tool functionality. That focus is understandable given the novelty, complexity and scale of such tools. However, several authors (Deal and Pallathucheril 2003; Pettit 2005) approach the topic from a qualitative angle, considering basic questions about the real-world relevance of specific PSS, such as:

- Are the tools useful, or even usable?
- Can they effectively support planning decisions and policy choices?
- Does the planning profession understand how to apply these tools?

The answers to such questions are important both for the shorter-term rate of adoption of these systems and for longer-term PSS acceptance within the planning and stakeholder communities.

The literature also conveys a sense that these systems and tools are being developed to meet functional requirements and use cases as conceived by the systems' developers. However, there is little evidence provided to indicate that deployment of these systems has informed development or that the use of these systems has

B. Deal (✉)
University of Illinois at Urbana-Champaign
Department of Urban and Regional Planning
611 Taft Drive, Champaign, Illinois 61820, USA
E-mail: deal@illinois.edu

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informed system development. In describing how a land-use model was operationalized for a regional PSS, Deal and Pallathucheril (forthcoming) suggest that embedding PSS development in real-world planning processes offers significant mutual benefits to both users and developers: the PSS informs the dialogue on regional planning while the application subjects the PSS to critical in-progress review and spurs developers toward further enhancements.

In this chapter, we elaborate on this idea of use-driven PSS development, which we distinguish from theory-driven development, based on our experience in developing and deploying *LEAM,* the *Land-use Evolution and impact Assessment Model*. First we briefly review the PSS literature and provide a succinct description of the *LEAM* process (Deal 2003; Deal and Pallathucheril 2007). Then we describe *LEAM*'s use-driven development by reviewing some of the policy-related questions that *LEAM* has been involved in testing. These policy reviews help to illustrate three key ideas about use-driven development:

- deploying a PSS during its nascent stages has significant benefits;
- addressing policy questions during system development is valuable; and
- developing a system can be as useful in planning as delivering the end product.

We conclude this chapter with a discussion of some of the difficulties inherent in use-driven PSS development.

2.2 Available PSS Tools

A growing set of PSS tools for simulating and evaluating large-scale urban dynamics have become available in recent years. Brail and Klosterman (2001) outlined the state of the art and described new approaches in PSS development that were, and continue to be, due in some measure to increased computational capabilities and availability of digital data. In their edited volume, the basic theoretical constructs and issues are examined by Batty, Harris, and Hopkins individually. A number of authors then describe a number of different PSS: *DRAM EMPAL* (Putman); *TRANUS* (de la Barra); *What if?* (Klosterman); *CUF, CUF II,* and *CURBA* (Landis); and *URBANSIM* (Waddell). A third section is devoted to issues of visualization.

To this body of knowledge, Geertman and Stillwell (2003) add a review of the role of PSS in planning with the intention of documenting best practices, promoting use of these tools and enhancing planning. They describe the evolution of PSS-like tools and identify spatially explicit tools (spatial decision support systems) as an important sub-category. The edited volume includes three discussions of planning processes: discussions of three tools used in each of a number of domains: participatory planning; strategic and land-use planning; and environmental planning. More recently, Klosterman (2005) has provided an update on the state of the art in a guest editorial in *Environment and Planning B* that attempts to define the types of PSS tools within a planning context in order to structure discussions of their utility. Klosterman describes categorizing PSS along two dimensions: by the planning task the model addresses; and the technique or approach it utilizes. Four techniques are recognized: (i) large-scale urban models – identified by their scale and the presence of spatial interaction markets; (ii) rule-based models – incorporate explicit decision rules that allow users to specify model behavior; (iii) state change models – use statistical methods to replicate geographic patterns without identifying underlying causes; and (iv) cellular automata (CA) – the least developed area of inquiry, combining rule-based and state-change dynamics over large-scale flat lattice grids. CA models provide an important basis for testing ideas and might find their way to useful applications in practice. At the time of this writing they appear extremely complex to build and operate and may be more useful as pieces coupled or integrated within other models (White and Engelen 1997; Wu and Martin 2002; Deal 2003).

This recent evolution of large-scale urban modelling towards dynamic spatial simulation systems contrasts somewhat with earlier work in spatial (and aspatial) reasoning systems (Kim *et al.* 1990). Knowledge-based reasoning systems are loosely based on a philosophical ideal of capturing the manner in which expert knowledge is applied to address complex planning problems. These systems are characterized by the use of multiple types of domain knowledge and complex domain models to support reasoning processes. This knowledge may include task and goal structures, various kinds of constraint, search control techniques and use of human expertise when necessary (Wilkin 2000). Almost two decades ago, Goel (1989) distinguished between case-based and model-based reasoning systems. In case-based reasoning, a body of known cases is assembled along with operations for inferring applicability to a particular situation; in model-based reasoning, inferences are drawn from a hierarchical abstraction of the system at hand. As with the present status of CA systems, future PSS work might employ integrated reasoning and dynamic simulation systems to help improve our ability to capture complex planning and implementation behaviors.

2.2.1 LEAM

LEAM is one approach to large-scale urban modelling and simulation that attempts to bridge the four categories described by Klosterman (2005). Similar to CA approaches, *LEAM* utilizes a structured lattice surface with state-change conditions that evolve over time. The *LEAM* lattice surface, however, is not flat and is shaped by biophysical factors (such as hydrology, soil, geology and land form), and socioeconomic factors associated with administrative boundaries, census spatial units and planning areas. As with state-change techniques, a probability is calculated for change of each cell from one land-use category to another. Unlike other state-change approaches, this probability is predicated on local interactions (e.g. the accessibility of the cell to a given attractor), global interactions (e.g. the state of the regional economy), and other mechanisms of causation (e.g. social forces). As with rule-based approaches, causal mechanisms are used to produce diverse planning scenarios. And akin to large-scale urban simulations, *LEAM* works at the regional scale with regional macro socioeconomic models combined within the *LEAM* modelling framework. Unlike other large-scale efforts, *LEAM* aggregates to the regional scale from a fine-scaled (30 × 30 m) resolution that includes cell-based micro models. This enables loose and tightly coupled linking with other models that might operate at a different spatial scale.

More detailed descriptions of the *LEAM* framework have been described elsewhere (Deal 2003; Deal and Pallathucheril 2007) and is not our intention to replicate these efforts. Rather, the intent here is to provide a very brief description of the basics of the model that will enable the reader to follow some of the reasoning behind its use-driven local applications. Fundamentally, the *LEAM* model consists of two major organizational parts: (i) a land-use change model (*LUC*) – defined by a dynamic set of sub-model drivers that describe the local causality of change and enable easy addition and removal of variables and the ability to play out 'what-if' scenarios; and (ii) impact assessment models that facilitate interpretation and analysis of land-use change depending on local interest and applicability – these help to assess 'so-what' questions and explicate the implications of a scenario. The need in planning and policy making to answer both 'what-if' and 'so-what' questions is a key basis for the *LEAM* framework.

In *LEAM*, the land-use transformation potential of individual cells is evaluated by explicitly quantifying the forces (drivers) that contribute to change. Understanding the causal mechanisms of change provide local decision makers an opportunity for testing policy and investment choices and are a critical component for completing scenario-planning exercises. Driver sub-models are locally dependent and derived through both analysis and local stakeholder interaction. An open architecture and modular design facilitates incorporation of additional local drivers needed to improve the explanatory power of the model.

A regional econometric, input-output model determines the regional demand for residential, commercial and open space land (Sarraf *et al.* 2005). Households and jobs are established and converted into land demand using sector-based economic and demographic analysis (in lieu of sub-regional constraints on demand to determine spatial allocation used in other approaches, such as Wu and Martin 2002). The estimated demand serves as a target for regional land allocation. Market variables increase or decrease development rates based on how well the regional demand targets were met or not met.

Simulated outcomes are described in graphs, charts, text and in map form and are used in engaging local dialogue and in analyzing the potential implications of the changes described. The environmental, economic and social system impacts of alternative scenarios can be modelled and tested (Deal and Schunk 2004). Scenario descriptions of alternative land-use policies, investments decisions, growth trends and unexpected events (among others) can be simulated, analyzed and compared for regional importance. *LEAM*'s visual and quantitative representation of each scenario's outcome provides both an intuitive means of understanding and a basis for analyzing the implications of potential decisions. These representations act as a catalyst for discussion and communal decision making.

For a particular region, *LEAM* evolves as an iterative process of data collection, model building, and dialogue. Local planners, policy makers and stakeholders provide feedback and input about the local salience and value of any given simulation. This feedback is gathered regularly and begins at project inception. It is used to more effectively capture the local condition, to provide a better local version of the tool and to inform local stakeholders about the tool and its uses. This form of use-driven modelling and system development, which takes place in very public forums, most distinguishes the *LEAM* approach. The authors believe, based on their experiences, that feedback and local dialogue are critical in the creation of useful PSS tools. Relying only on theory or the underlying mathematics does not tell a complete or even (at times) a compelling story about local conditions. Constant internal and external review and interaction are critical to informing both the modeller and the local stakeholders of modelled changes, improvements and scenario outcomes.

2.3 Use-Driven Simulation Model Development with *LEAM*

Application of a robust analysis tool like *LEAM* provides a rich source of data and information for a region. In applying *LEAM* in diverse contexts, we have found numerous occasions where this wealth of information has been used to specifically inform policy deliberations. In our use-driven, feedback-based process of model and system building, *LEAM* simulations inform policy deliberations. Policy deliberations call for more and better information, which in turn drives additional *LEAM* enhancements and refinements (that find their way to other policy deliberations). In this section, we draw on three examples to illustrate this mutually beneficial use-driven, feedback-based relationship. One example considers how visioning exercises can be more thoroughly grounded, another looks at assessing alternative transportation investment choices, and the third considers an environmental planning task. Each draws on *LEAM*'s inherent ability to quickly provide useful information and a forum for dialogue. In terms of model refinements, the first example required simulating alternative scenario futures, the second required loosely coupling *LEAM* with a separate model to inform deliberations, and the third required developing and refining a separate, but integrated model.

2.3.1 Grounding a Regional Vision

In 2001, the Northeastern Illinois Planning Commission (NIPC) embarked on an effort to engage the Chicago region in a bottom-up planning effort that culminated in the *2040 Regional Framework Plan*. An important aspect of this effort was *Common Ground*, a process to build regional consensus: ‘Common Ground engaged a cross-section of people in the City of Chicago and the six-county region: residents, community leaders, public officials, business owners and planners at all levels. Nearly 4,000 people participated in 200 local and regional workshops and meetings across northeastern Illinois. These public meetings, combined with specialized work by a range of planning experts and elected officials, identified local and regional assets, needs, and challenges' (NIPC 2004: p. 6).

This multi-year effort produced an impressive set of 52 regional goals and associated objectives that addressed issues ranging from 'education to water supply, transportation to taxation' (NIPC 2004: p. 11). This diverse set included goals such as protecting natural resources, enhancing social equity and preserving economic competitiveness. A framework of centres, corridors, and green areas was formulated as the region's way of growing towards these goals. With this framework in place, the region's planners were faced with the need to ground their visions of the future in a manner that could be conveyed to the public in a tangible and meaningful way. To address this challenge, they commissioned two simulations of future land-use change using *LEAM*. A *Baseline* simulation played out current development patterns and trends into the future; a *Future Framework* simulation implemented the idea of centres, corridors and green spaces. Rather than the simulations themselves, it was expected that the comparison between the two would make clear the differences between the current trajectory of regional change and the alternative future envisaged by NIPC staff.

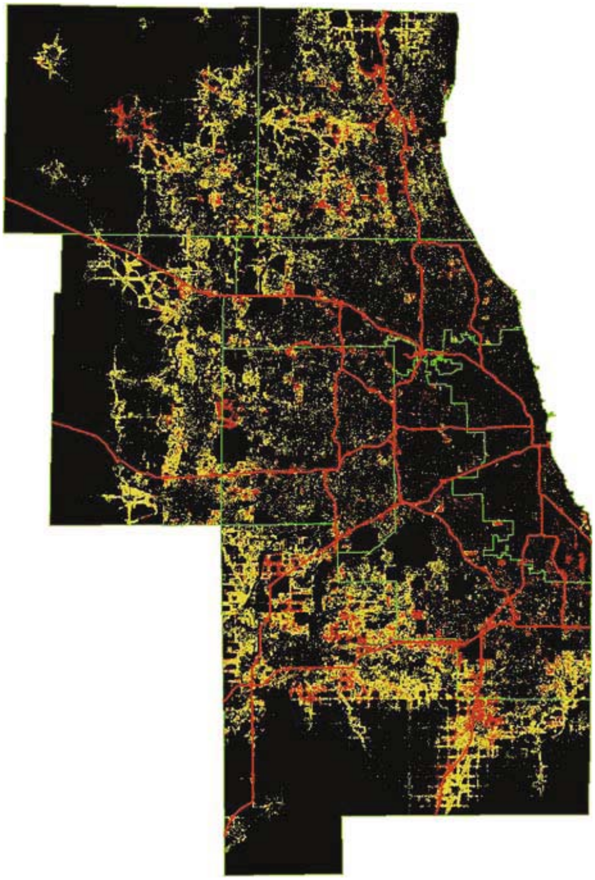

Fig. 2.1 Land-use change in the Chicago region: *Baseline* simulation (See also Plate 2 in the Colour Plate Section)

The typical *LEAM* protocol was followed. A preliminary set of simulations was created in about a month using a limited set of drivers and nationally available data sets. These simulations were reviewed with NIPC staff and some key problems with these simulations identified: for instance, development was occurring in unlikely places such as parks and recreation areas not identified in the national data. To remedy these kinds of problems, NIPC staff produced land-use and other data that better reflected current conditions. Model parameters were adjusted in *LEAM* to better reflect current development patterns in the Chicago region. A reasonable *Baseline* simulation was generated with these refinements to *LEAM*. Figure 2.1 is the map created to show the change in land use over the 40 year time period modelled. Figure 2.2 is a graph showing annual land-use change in each of the region's six counties; note that growth is neither linear nor necessarily sustained over time.

With the *Baseline* simulation as a reference, the *Future Framework* was simulated: places identified as population centres were made more attractive to residential development; places identified as jobs centres were made more attractive to industrial and commercial development; proposed transportation corridors made some parts of the region more attractive to future development than in the *Baseline* simulation; designated green areas were not available for development. Specific allocations to parts of the region were not made; rather various locations in the region had to compete for growth based on changes in the underlying drivers. This approach was developed through intense consultation with NIPC staff and others; it was not easily arrived at. Here too, periodic review with NIPC staff produced valuable insights: for instance, development was not occurring in brownfields as envisaged because the national data did not indicate that these areas were functionally obsolete.

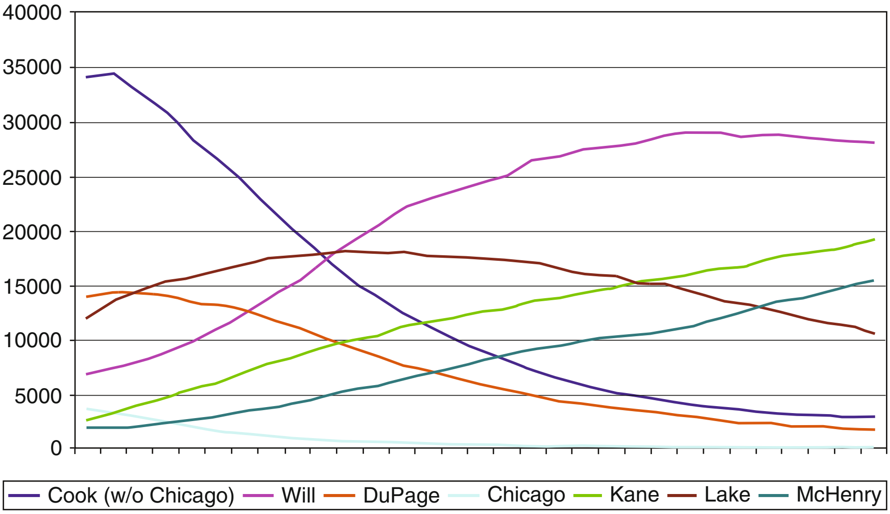

Fig. 2.2 Annual land consumption by county: *Baseline* simulation (See also Plate 3 in the Colour Plate Section)

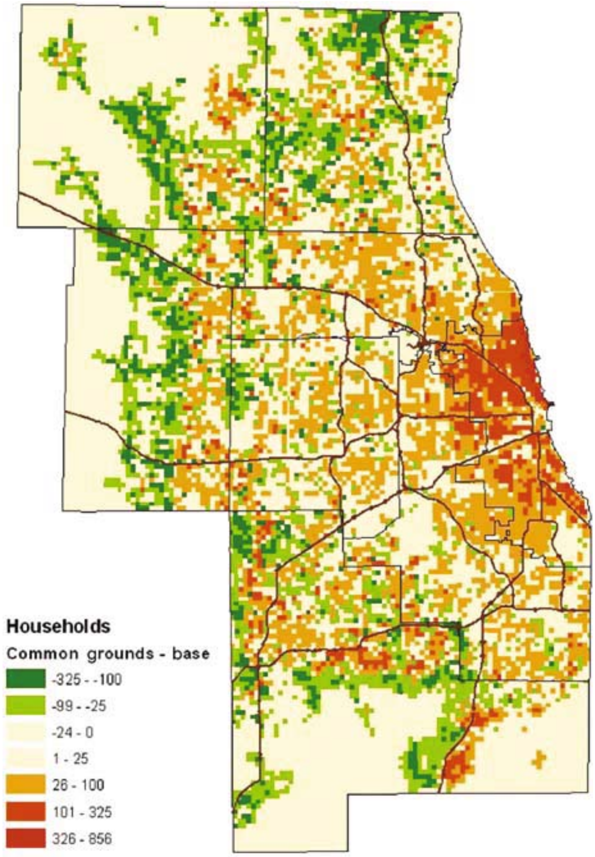

Fig. 2.3 Difference in household location between *Baseline* and *Future Framework* simulations (See also Plate 4 in the Colour Plate Section)

Comparing various aspects of the two simulations allowed planners to highlight some stark differences. Figure 2.3 shows differences between the two simulations in terms of location of new households. Green areas in the map have more *Baseline* households, while red areas have more *Future Framework* households. The *Future Framework* appears to pull residential development away from peripheral regions. Figure 2.4 shows the differences between the two simulations in terms of location of new jobs. Again, green areas have more *Baseline* jobs, while red areas have more *Future Framework* jobs. The *Future Framework* appears to pull jobs to a few locations in the inner ring of suburbs. Figure 2.5 shows agricultural land and unprotected open space lost in the two simulations. The difference varies by county, but all counties will see fewer acres of these lands lost as a result of development under the *Future Framework*.

The quick turnaround on the first set of simulations, and the weekly review of changes being effected in simulations, meant that NIPC staff were kept engaged with questions about the dynamics of land-use change in the Chicago region. Unexpected outcomes were not always attributable to shortcomings in the model or the underlying data. Rather, these outcomes challenged preconceived notions and facilitated

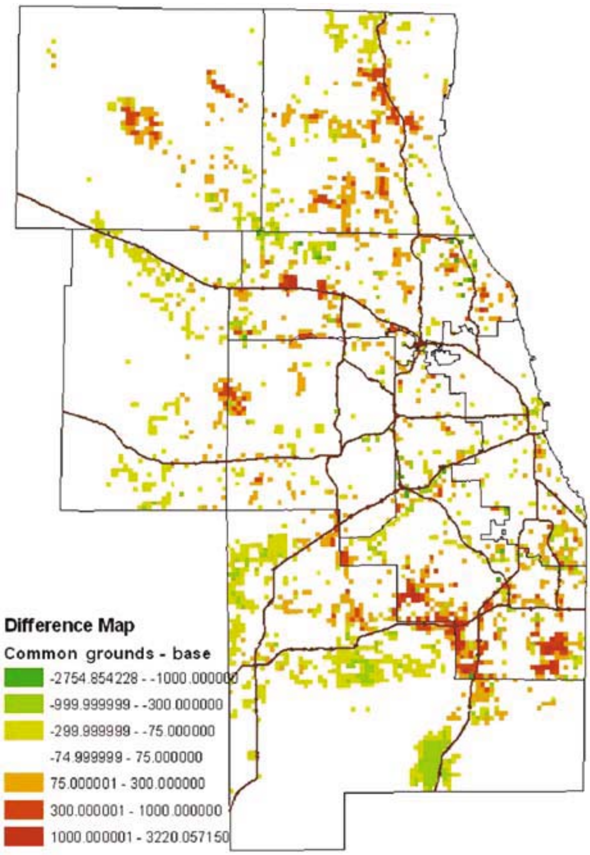

Fig. 2.4 Difference in job location between *Baseline* and *Future Framework* simulations

new insights about the region. For instance, most simulations showed more development in Lake County than NIPC staff expected. It emerged in discussions that Lake County has placed stringent restrictions on new development, and that was why the outcome appeared unexpected. The outcome brought to the surface some important

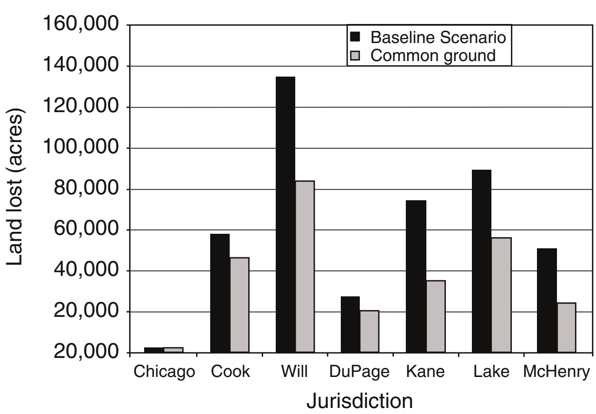

Fig. 2.5 Difference in consumption of agricultural land and open space by county

ideas that remained under the surface: Lake County is a very attractive place for development, and the restrictions placed in Lake County are pushing development to other locations in the region.

2.3.2 Assessing Transportation Investment Alternatives

The application of *LEAM* to the two-state, ten-county region around St. Louis, Missouri (MO), is a great example of a long-term, use-driven, embedded modelling effort with real implications for the process of planning in the region (Deal and Pallathucheril 2007). In 2003, the East-West Gateway Coordinating Council (EWGateway), the Metropolitan Planning Organization (MPO) and council of governments for the St. Louis region, began to use *LEAM* (in a version later called the *Blueprint Model*) as a platform for encouraging a regional dialogue on issues of economic development, social equity and environmental sustainability. Based on prior experience in the Peoria tri-county region (Deal and Pallathucheril 2003), instead of initializing the process with a lengthy model-building exercise, the initial focus was set on quickly producing a set of simulations. This quick-start process served two purposes: to quickly begin the process of engagement and build interest; and to collect information from the local stakeholders on the state of the local condition for model localization. These early simulations were subjected to public scrutiny in workshops, meetings and other public forums. Participants in these forums provided valuable insights into the dynamics of urban land-use change in the region and a direction for future modelling efforts. Conducted on an annual basis, they also provided an excellent platform for dialogue among participants.

One early critique of the preliminary *LEAM* simulations presented was aimed at the way in which new development was being distributed across the two sides of the Mississippi River – the Illinois side on the east, the Missouri side on the west. Preliminary simulations showed considerable new developments in Illinois relative to Missouri; at the same time, the central business district is in Missouri and has historically seen the bulk of new development. These simulations utilized posted travel speeds in some sub-models simulations were utilizing posted speeds and did not take into account the difficulty of crossing into the CBD. When observed, congested speeds were used to measure travel time (taking into account how traffic congestion makes portions of the region more or less attractive), simulated development shifted from the Illinois side to Missouri. A major factor was the effects of congestion on bridges and the approaches to them (bridges represent severe choke-points with very little opportunity for alternative routing). Figure 2.6 shows the change in an area's access to large-scale employers when bridges are crossed at (a) posted speeds versus (b) slower speeds due to traffic congestion. In the regional dialogue, this outcome highlighted the critical role played by bridges in the distribution of new development across the region.

To better connect the two sides of the region, the construction of a new Mississippi River bridge has been the subject of planning studies, preliminary design and environmental impact analysis for over 20 years. A concerted civic and political

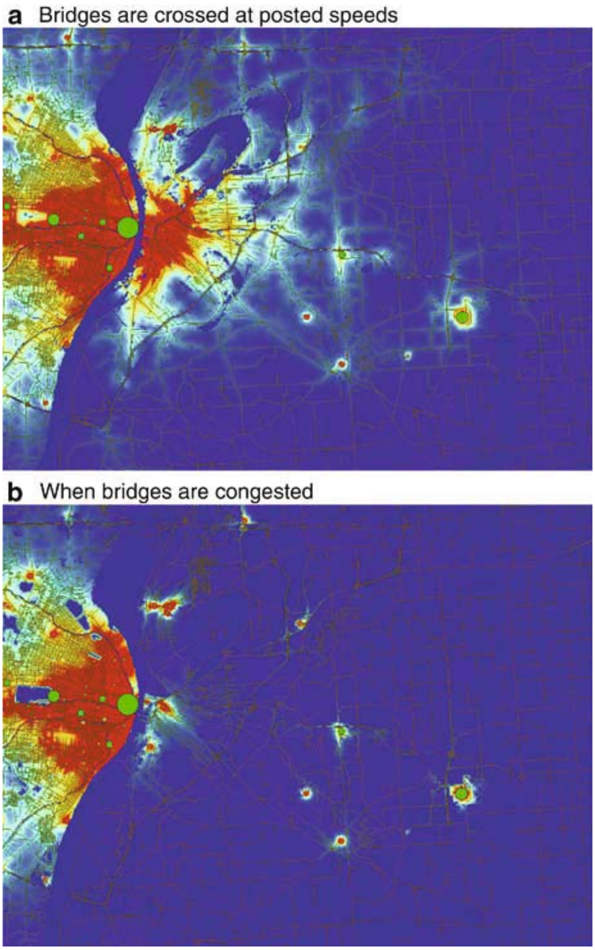

Fig. 2.6 The change in the attractiveness (red is high – blue is low) of large scale employers in the regions (*green dots*) when (a) bridges are crossed at posted speeds and (b) when they are congested (See also Plate 5 in the Colour Plate Section)

effort to secure earmarked federal funding was only partially successful. The resulting funding shortfall called into question the original bridge proposal and how it would be implemented. Alternatives considered included covering the shortfall with a toll and constructing less expensive alternatives such as enhancing the capacity of an existing bridge; there was no regional consensus on the way forward. Facing a stalemate on the issue, EWGateway took the lead and sought to inject an analytical basis into the regional debate. In order to do this, however, it became crucial to go beyond traditional cost-benefit analyses and to jointly simulate and analyze future transportation and land-use consequences of the different choices.

The desire for jointly modelling land use and transportation had emerged early in applying *LEAM* to this region. In the process of localization, future land-use changes were translated into changes in people and jobs across the region. The implications of these refinements presented EWGateway transportation planners and modellers with a more rigorous basis for determining future travel demand in the region. It allowed them to effortlessly and systematically assign future population, households and jobs to traffic analysis zones (TAZs), and to have this assignment reflect different future scenarios. The approach they previously employed evenly distributed new households and jobs across the region; *LEAM*-generated patterns were spatially varied and provided richer, more meaningful spatial data (in *LEAM* simulations, TAZs with new development can still lose population and jobs as a result of declining household size and increasing productivity).

With input from land use into the travel demand model in place, the next step was a loose coupling of *LEAM* and EWGateway's custom-built travel demand model, *TransEval*. Essentially, results from *TransEval* are used as inputs into *LEAM* which is run for several annual time steps, the resulting land use is the basis for socioeconomic inputs back into *TransEval*, and the process iterates until the simulation is complete. Each model helps address a limitation in the other. A travel demand model like *TransEval* can provide *LEAM* with indicators of travel conditions (congested speeds) that can continually change in response to changing land-use conditions. *LEAM*, on the other hand, can provide *TransEval* with changes in households and jobs in TAZs that respond to changes in the performance of the transportation network. This loose coupling is described in greater and more technical detail in Pallathucheril and Deal (2007).

Three simulations were created by coupling *LEAM* and *TransEval*. In all three simulations, *LEAM* was first run from 2000 to 2014, when construction of all the four alternatives is expected to be completed. At this point, the distribution of people and jobs from *LEAM* and different changes in the transportation network, representing each of the four alternatives being considered, were used as inputs in *TransEval*. Travel speeds on the transportation network estimated in *TransEval* as a consequence of these inputs showed differences across the alternatives. The resulting changes in travel speeds and the changes in demand for land (a function of the

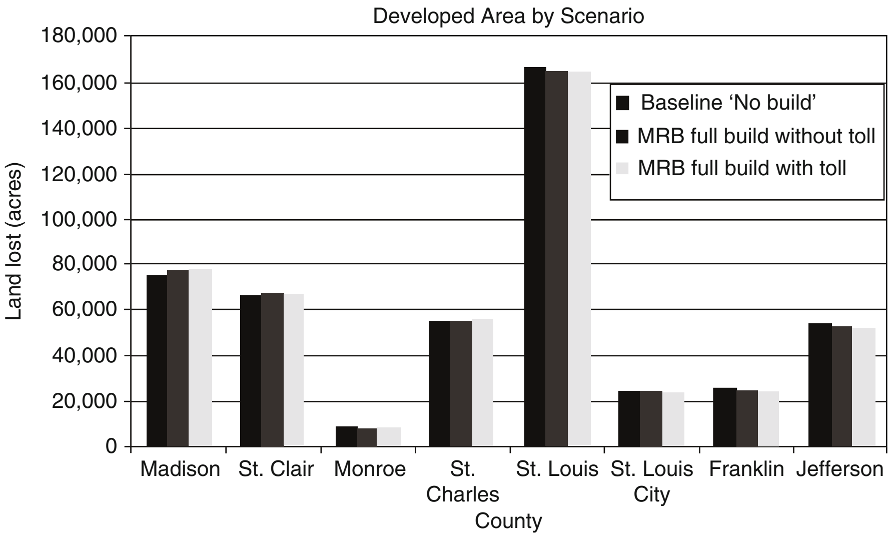

Fig. 2.7 Variations in land consumption, by county, across three simulations

impact of investment in each of the alternatives) were used as inputs in *LEAM* simulations of land-use change out to the year 2040. Differences between alternatives in terms of attractiveness of locations in terms of accessibility to jobs and urban amenities, and differences in the demand for land, produced different land-use outcomes in the year 2040.

The land-use, economic and transportation outcomes in the three simulations, and those of a baseline *No-Build* simulation, were the basis for informative comparisons. Figure 2.7 summarizes differences in land consumption by county among simulations associated with two alternatives (the original bridge design with and without imposing a toll) and the baseline *No-Build* simulation. Differences appear to be slight: building the bridge appears to slightly increase development in Madison and St. Clair counties and slightly decrease development in St. Louis and Jefferson counties; imposing a toll increases land development in St. Charles county. Figure 2.8 displays differences in land-use change between the *Full Build* and *No Build* simulations at a finer resolution; red cells see more growth in the *Full Build* simulation, green cells see more growth in the *No Build* simulation. The map presents a more complex set of differences and suggests that aggregating to the county level masks greater change: while building the bridge facilitates greater land development in the Illinois side of the region and takes away from development on the Missouri side of the river, there are significant differences in development at the local level.

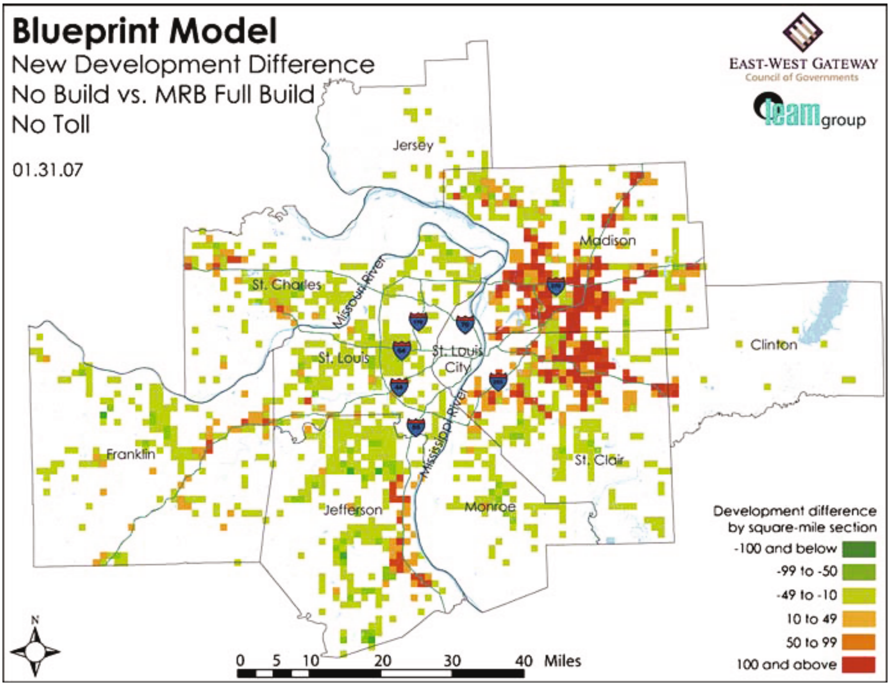

Fig. 2.8 Differences in land-use change between *Full Build* and *No Build* simulations (See also Plate 6 in the Colour Plate Section)

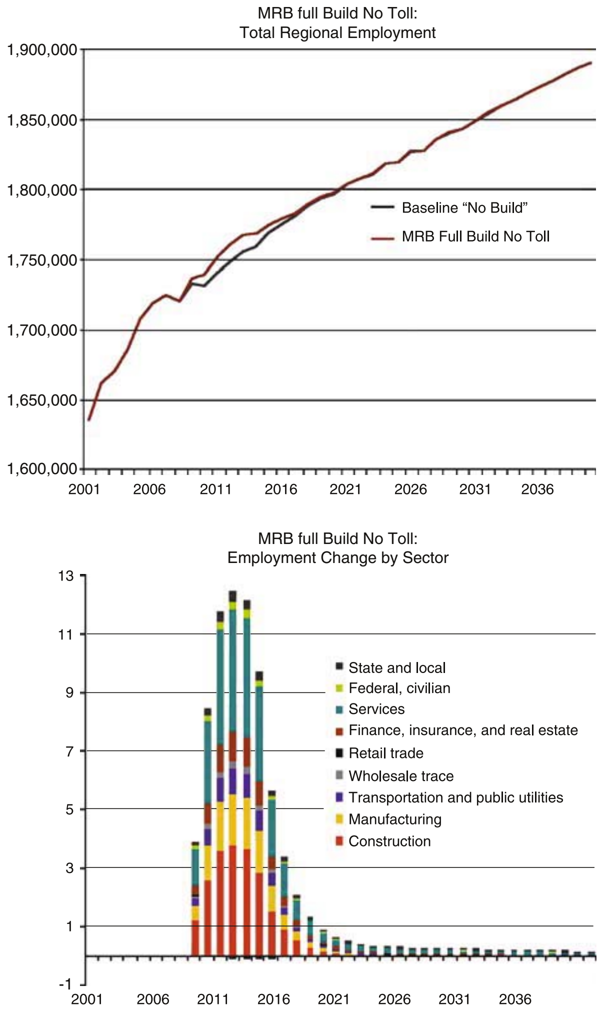

Fig. 2.9 Impact of the *Full Build* alternative on the regional economy

Differences in land-use change between the two simulations also result from greater amounts of land being consumed in the *Full Build* simulation as a result of expansion of the regional economy due to investment in bridge construction. This impact is summarized in Fig. 2.9. Beginning in 2009, the region will see an increase in jobs across different sectors as a result of bridge construction; after 2014, once the bridge is complete, the impact on the economy gradually attenuates.

Coupling the two models allows assessment of travel consequences of the different alternatives. Figure 2.10 presents a comparison of total time spent traveling from Missouri to Illinois (MOTOILVT) and Illinois to Missouri (ILTOMOVT); constructing the original bridge proposal and imposing a toll to cover the budget shortfall would increase travel times considerably.

As might be expected, discussions around these simulations and what to make of them were quite intense (and the regional dialogue is as yet unresolved). Some

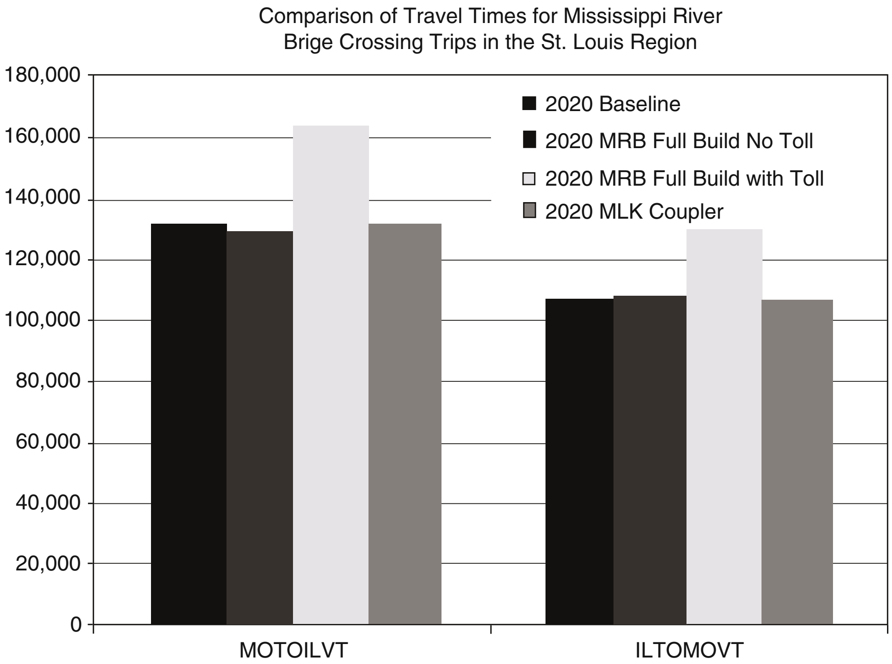

Fig. 2.10 Variations in total travel times across four simulations

outcomes appeared counter-intuitive; imposing a toll on the bridge increased total travel times in the region. Working through the complex interactions suggested a striking explanation; the toll was diverting traffic to the other bridges across the river that do not impose a toll, increasing congestion on these bridges, and increasing travel times. This explanation brought into question the wisdom of using a toll to cover the budget shortfall. There were other insights generated: patterns of land-use change are likely to change if additional river crossings are built; land-use policies and controls must be put in place in these areas to manage these impacts. Ultimately, however, only slight differences were uncovered even though the magnitude of the investment required for each of these alternatives is very different. This suggests that perhaps the lowest cost alternative is preferable, but it also suggests that demand-side tactics, such as investing in a better regional jobs-housing balance, might be more cost effective.

2.3.4 Planning Wildlife Corridors in an Urbanizing Region

The application of *LEAM* to the tri-county region around Peoria, IL, was one of the first involvements with a regional planning effort (Deal and Pallathucheril 2003). In 1999, regional planners from the three-county region surrounding Peoria and the Illinois Department of Natural Resources began studying the rapid land-use transformation in the region (Tri-County 2001). The concerns about transformation ranged from unplanned growth and natural resource depletion to low-density development and traffic congestion. The planners gathered spatial data, analyzed regional growth and apparent trends, and compared their data with historic spatial information. The group then generated explanations for the patterns that emerged from the analyses, and also developed general ideas about development impacts. However, a number of central questions remained unanswered for the group, namely:

- What should be done next with the information?
- What are some of the future impacts of current or alternative policies and decisions?

Through a collaborative process involving university researchers, state and local officials, and local stakeholder representatives, a version of *LEAM* was refined specifically for local application to the Peoria region. Scenarios were developed that described current and alternative policies and investment choices. Outcomes were used to visually examine and understand the spread of development in the region as well as probable environmental, social, and economic impacts of the different scenarios. An opportunity to leverage this work presented itself when the region sought to designate and protect wildlife corridors. The loss of habitat suitable for supporting populations of different species at their current or desirable levels is one particularly undesirable consequence of urban development. It is not so much that the amount of habitat is reduced; rather, it is change in both the amount and the spatial configuration of habitat. The same amount of habitat distributed across space in very small patches will likely support a smaller population.

LEAM simulations were used to study the threat from urban development to bobcat and wood thrush populations in the region. (The underlying technical basis for this work is available in Aurambout *et al.* 2005.) The advisory committee charged with directing the project considered the question of the species on which the study should focus. In the interest of keeping the number of species to a manageable number, the committee decided to focus on the bobcat and wood thrush populations. By choosing these two species the committee expected to cover the habitat suitable for supporting many of the other species found in the region. The threat to the bobcat and wood thrush populations from urban development was assessed in two steps. First, the amount and location of habitat suitable for each species was assessed using land-cover data from the year 2000. Second, this spatial distribution was assessed against land-use change as simulated up until 2030 using *LEAM*. Several *LEAM* simulations were used: three economic futures (business as usual, economic decline, and a high economic growth scenario), and high growth combined with different policies (agricultural land preservation, river bluff protection and limiting growth to areas currently served by infrastructure).

The highest decrease in suitable habitat, and the biggest impact on the bobcat population, occurs when high growth is combined with restricting future growth to areas currently served by infrastructure known as facility planning areas (FPAs). This is termed the *High Growth Contained* simulation. While the impact of high growth was only to be expected, the impact of restricting growth to FPAs was not.

Table 2.1 Total area of suitable core habitat (hectares)

Core habitat	Initial condition	Business as usual	Economic decline	High growth Redirected	Bluff protect	Contained
High home range	18,441	17,500	18,352	17,327	17,251	16,790
Average home range	24,086	23,701	23,979	23,459	23,350	22,931

Discussions of this surprising outcome with the advisory committee and local planners revealed that FPAs contain the largest forest patches most suitable as bobcat habitat, and brought into question the original basis for laying out FPAs.

The dynamic spatial model underlying this analysis allowed the sensitivity of these findings to be assessed. We looked in particular at the assumption of habitat requirement and considered two different assumptions: (i) high habitat requirements; and (ii) average habitat requirements. Table 2.1 describes the amount of suitable core habitat available across several simulations. As mentioned earlier, the *High Growth Contained* simulation results in the greatest reduction in core habitat. The underlying model developed for this analysis also allowed the population of breeding females to be estimated based on data concerning female bobcat territoriality. Table 2.2 shows that changes in land-use policies could potentially affect 10–15 per cent of the total potential bobcat population. Although a small sample set might skew the results, this may be a significant effect when dealing with threatened populations.

Figure 2.11 displays the areas of habitat lost in the *High Growth Contained* simulation. Lighter shaded areas on the map are habitat patches that remain after land-use change; darker shaded areas represent original habitat patch that is lost as a result of land development. Loss of habitat occurs in significant amounts to the north and south of the city of Peoria; there is a small patch of loss to the west of the city. In Fig. 2.12, we zoom in on the area north of the city: mid grey denotes bobcat habitat, lighter grey denotes existing developed land, and darker grey denotes land likely to develop in the *High Growth Contained* simulation.

Table 2.2 Potential number of bobcats hosted within home ranges (based on female territoriality)

Core habitat	Initial condition	Business as usual	Economic decline	High growth Redirected	Bluff protect	Contained
High home range	30	29	30	29	29	29
Average home range	35	34	34	33	33	33

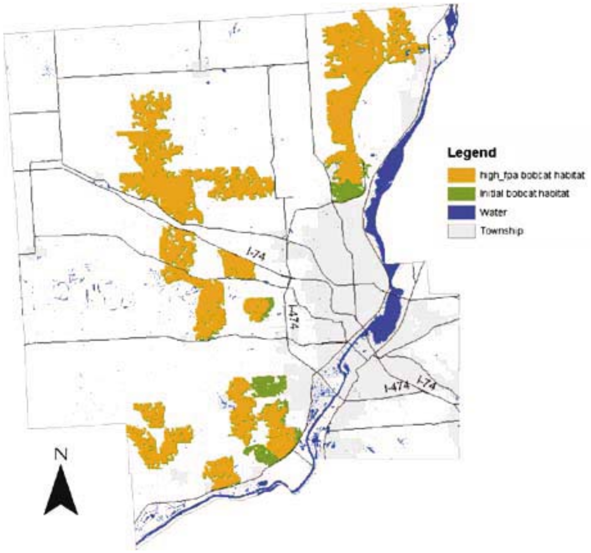

Fig. 2.11 Bobcat habitat lost (darker shaded areas)

Extending this analysis, we also overlaid habitat patches lost under all scenarios. In this way, we were able to identify patches that were likely to be lost in more than one simulation. Using this information, we were able to identify high-priority patches likely to be lost in all simulations as well as those that were threatened in fewer simulations. A number of patches that were not threatened in any simulation likely would require minimal attention. Using this information, conservation and land acquisition were prioritized in areas that are likely to be most threatened and would also contribute the most to connecting and expanding existing patches.

Future consumption of land for development reduces habitat suitable for supporting populations of native and/or threatened species. In some instances, the

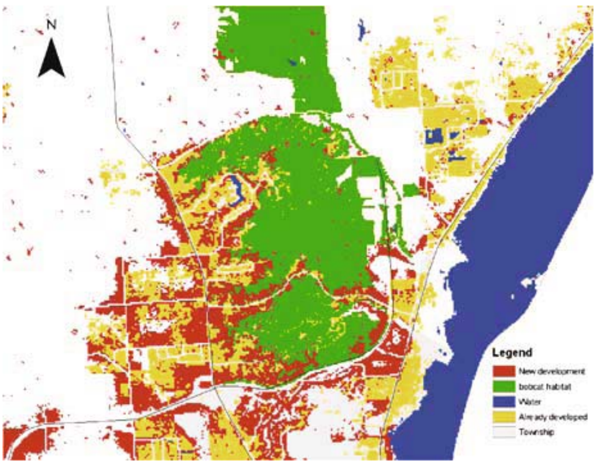

Fig. 2.12 Detail of bobcat habitat lost

amount of habitat lost may not be as critical as where these losses occur. The spatial configuration of bobcat habitat is critical to its survival. High-quality patches, when surrounded by urban development that is difficult to traverse, might limit the genetic diversity of the local bobcat population. We were able to demonstrate to local stakeholders the value in using spatially explicit analyses. With *LEAM* simulations, they were able to visually see and participate in dialogue on potential policy levers and investments that might limit the fragmentation of bobcat habitat in the region. This led to discussions of implementing low-impact developments (LID) in specific parts of the region with protected corridors and greenways to enhance and connect high-quality habitat and limit its loss (Hopkins 2005).

2.4 Some Lessons Learned

Two of the key lessons learned in integrating *LEAM* with regional and local planning processes:

- *LEAM* is unlikely to succeed as a standardized, off-the-shelf product, and is mainly useful when customized as a localized application for the specific region of interest.
- Discussions about simulation results, including deficiencies, add considerable value to regional planning dialogue. Therefore, even ‘quick and dirty’ results can be very useful when planners, stakeholder representatives and decision makers work cooperatively to interpret them through the lens of expertise and local perspective.

Simulation results become an important part of the dialogue on transportation networks and other investment strategies. Simulation results offer a rich set of data that describe important relationships between growth pressure and investment choices. In places where growth pressure already exists, infrastructure investments can cause dramatic swings in growth (usually positive if not regulated). In places where the development pressures are not in place, infrastructure investments appear to have little economic growth benefits. Upon reflection this can be anecdotally surmised. If an interstate ramp is constructed in a rural area with low growth pressures, development from the investment may be limited to gas stations and other small, auto trip related developments. If an interstate ramp is constructed in a place with high growth pressures however, development as a result of the ramp investment can have large implications (perhaps like removing one’s finger from a dike).

Using *LEAM* to test planning policy and investment decisions requires that local decision makers accept modelling, and more specifically the *LEAM* model, as a valid tool for understanding the local condition. The process of gaining acceptance and of becoming an integral part of local and regional planning evolves with time and familiarity (Deal and Pallathucheril 2007). A use-driven, embedded approach to local model development suits this evolutionary process. Our experiences in embedded modelling, as described in the policy questions presented, reveal some key lessons for operationalizing components of a regional PSS.

- There is value in embedding model and system development in real-world planning and policy making. Models are typically built by experts who work behind the scenes. By modelling in the public eye, the technical and analytical choices being made are subject to intense and valuable scrutiny that can foster improvements. Black-box approaches have limited value under these circumstances.
- The fundamental value of building models and PSS is that they foster thought experiments, the ability to test important investment and policy choices and discuss their potential future outcomes.
- There is a need to engage in the relevant dialogue among regional stakeholders very quickly. Even preliminary results, if they represent a tangible basis for discussion, not only enhance the regional dialogue but also help kick-start the building of a PSS.
- Some of the effects of embedding in planning and policy making may appear small but these are nonetheless important. An intervention may only reveal that further analysis is required, but doing so may slow the rush towards a poor choice.
- The process of model and system building is just as important as — if not more so than — the model itself. As a result, the precision or rigour of a model may be less of an issue than its ability to foster dialogue and produce useful results.
- There is value in being able to consider multiple futures rather than having to choose a single desirable future condition. We have argued this elsewhere (Deal and Pallathucheril 2007a). PSS should provide data and metrics that help stakeholders discern important differences among these multiple futures.

2.5 Conclusions and Future Efforts

Large-scale urban simulation models are being developed that enable planners and stakeholders to view and assess the future outcomes of current policies, and investment choices before they are put into action. But unlike our improving ability to create these complex planning support systems, the process of putting them into practice, gaining acceptance and becoming a part of local planning has been more difficult. We have argued here, through the use of examples from our experiences using *LEAM,* that a use-driven, embedded approach to local model development can help to speed up and improve this process. These applications revealed some key lessons for developing and implementing a regional PSS, including the fact that early and continued engagement and feedback are critical; and that embedding model development in real-world planning and policy questions is important for shaping tools that user groups will implement. We also found that the process of model building is just as important as the model itself because it provides insight and dialogue that may not otherwise take place; and that in an increasingly chaotic world, the ability to produce, analyze and discuss multiple futures is critical for effective decision making.

Better tools are needed to manage regional dynamics, not just as economic systems or static inventories of resources, but as complex systems that are part of regional and global networks (Campbell 1996). Effective decision making requires that we understand the systems to be administered and that we understand the future implications of our proposed strategies. We have attempted here to outline an approach for understanding the dynamics of urban systems and the potential implications of urban policy and investment management decisions. We described one modelling approach – *LEAM* – that utilizes technological advances in spatial simulation modelling to help improve a region's ability to make sound decisions. *LEAM* was intended to enable users to deal with stochastic influences and view the reported probable consequences of intended events in a scenario-based format that is comprehensible by local experts, decision makers and stakeholders.

Successful use of tools like *LEAM* requires that local decision makers accept the modelled outcomes as reasonable. The process of establishing 'reasonableness' and gaining acceptance unfolds over time. We believe that use-driven, embedded approaches will provide the basis for crafting a unique, local view of regional development problems, issues, and processes; that achievement, in turn, will be valuable both in gaining the necessary stakeholder acceptance and in promoting the effective implementation of policies based on consensus.

LEAM is a product of an academic laboratory. As such, a purpose of *LEAM* is to support the laboratory's underlying mission of advancing the science of modelling and the practice of planning. Ultimately, such advances must be verified in the 'laboratory of the real world', where planning decisions actually matter and have consequences for governments, regional planning authorities and their diverse constituents. That verification process necessarily involves ongoing relationships with end-users and repeated applications in multiple locations. The process is essential, but in itself it does not promote further advances in the state of the art. Lessons learned from real-world applications provide crucial input to further investigations and advances in the *LEAM* Laboratory. Progress may be encumbered when either phase of research and development is overemphasized.

In order to better exploit synergies between our basic research and applications, we have established an associated private-sector entity whose purpose is develop new, straightforward localized applications; provide technical support; and sustain long-term relationships with established *LEAM* users. At the same time, the purview of the *LEAM* Laboratory continues to be fundamental questions of urban land-use change and its implications. The laboratory concerns itself with advanced theoretical topics, emerging simulation modelling technologies, and new ideas about the potential of regional planning for helping to foresee and solve development problems before they become stubborn realities. This synergistic relationship requires considerable coordination and oversight, but it provides a positive and dynamic environment for future advances and problem solving.

Our embedded, use-driven approach to developing *LEAM* points to the need to address the following topics in future research:

- informing dynamic, continuous planning in other domains (such as watershed planning) based on the experience with embedding a PSS in regional planning;
- operationalizing and modelling the feedback from land-use change to regional economic change;

- developing a generic specification and framework for loosely coupling models based on the experience in coupling land-use and transportation models;
- supporting easy extraction of knowledge from burgeoning data sets that contain growing suites of land-use simulations of increasing complexity and resolution;
- leveraging the World Wide Web and other Internet technologies to democratize access to and enhance usability of the *LEAM* PSS; and
- deploying *LEAM* effectively on user desktops.

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