

Modelling Behavioural Responsiveness in City Structuring

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Abstract: There is a growing imperative for infrastructure decisions in Australia to be based on evidenced based approaches which are data driven. Urban growth modelling is increasingly being used in strategic infrastructure planning practice. However, current models tend to be "once-off" applications based on static equilibrium approaches that represent little or no behavioural validity. To increase the uptake of urban models to support infrastructure planning we argue these models need to become more responsive to a more complex, multi-modal and demand-side policy environment, founded in behavioural and complexity sciences but also need to be facilitative of participatory planning approaches. This paper presents a critical review of two case study applications of alternative land use modelling approaches in the context of Australian local government areas, assessed against an evaluation framework developed from a set of best practice modelling criteria, sourced from the international literature. The first case study is an application of the more complex, detailed, agent-based model, UrbanSim, in Logan, Queensland (Qld) and the second, the more simple, rule-based model, Online What-if?, applied in the North-West subregion of Perth. These contrasting approaches are considered in terms of their performance in incorporating behaviour in relation to both internal model functionality and in terms of responsiveness to and interaction with the external user environment. Insights are offered into the trade-offs made in practice and what the learning is in relation to reconciling seemingly competing objectives of simplicity for better interaction with external users and complexity for better responsiveness to changing policy and behavioural responsiveness.

Introduction

Urban Growth Models in Infrastructure Planning

Transport, communications, utility networks and land use are considered the most permanent elements of the physical urban system with a "very slow" rate of change (Wegener, 2004). Large infrastructure projects require a decade or more to implement and once in place are rarely abandoned. The land use distribution is equally stable, only changing incrementally. This permanence, together with significant capital and ongoing operating costs, makes land use and infrastructure decisions particularly critical for city managers. Understanding potential impacts before committing to infrastructure investment becomes an important part of the decision-making process. Impact assessment supported by urban growth modelling is often a requirement for infrastructure funding applications across all levels of government. Urban growth modelling is increasingly used to forecast the type, scale, location and timing of residential and non-residential development, forming the basis of infrastructure planning. In Australian cities, in practice, land use inputs to infrastructure planning are mostly derived through some form of population and employment trend forecasting, not strictly regarded as urban growth modelling as it does not attempt to simulate an urban system. There are a limited number of urban growth modelling applications in Australia at the local government or city scale reported in the academic literature (Brits, 2013; Brits *et al.*, 2013; Chhetri *et al.*, 2007; Pettit 2005; Pettit *et al.*, 2008; Pettit *et al.*, 2015; Stimson *et al.*, 2012; Wilson, 2011; Bell *et al.*, 2000).

Defining Urban Growth Modelling

In practice and in the literature, a number of related and sometimes interchangeable terms are used in relation to urban growth modelling, e.g. land use modelling, land use change model, urban simulation,

land use forecasting, scenario modelling, integrated land use-transport modelling. The term *urban growth modelling* is used here to describe mathematical representations of functions and dynamic processes and interactions which generate [mostly urban] spatial structure in terms of land use, usually embodied in computer programs, to analyse and forecast the development of urban land use systems (Wegener, 1994; Waddell & Ulfarsson, 2004; Batty, 2009, p. 51). Land use-transport modelling interactions are well-developed and although the focus in this paper is on the land use modelling side, the strength and reciprocity of impacts between land use and transport systems need to be considered. Without exception, the urban growth modelling referred to here is at a strategic level applied to large urban systems even though they may be built up of many, small zones or parcels and can be used to investigate the impact of smaller sub-urban development proposals, as well as local government and metropolitan-wide policies and programs.

Changing Approaches to Urban Growth Modelling

Urban growth modelling approaches have evolved not only as a result of technical and mathematical advances, but also as urban realities and theoretical conceptualisations of cities have changed. Prior to Lee's watershed "Requiem for large-scale models" (1973), which predicted the demise of large-scale urban models, models were predominantly top-down, deterministic and not implemented as part of a deliberative planning process. At this time, cities were based on industrial economies and conceptualised as simple systems with a finite number of weakly interacting individual elements (Sui, 1997). Cities were seen as stable structures with dominant functions occurring in the central business district. Urban planning was institutionalised to deal with the problems of industrial and population growth, using a top-down, location control zoning approach.

Models post-Lee (1973), after a hiatus in model development in the 1970's and 80's, were developed on the basis of the evolving conceptions of cities based on knowledge, as organic, complex-adaptive socio-ecological systems, with large numbers of individual, intelligent, self-organising, adaptive agents, continually modifying their behaviour in response to new information. Interactions between agents are pre-eminent and generate unexpected outcomes. Models are accordingly now increasingly being based on non-linear dynamics, chaos theory, fractals, cellular automata and neural computing and are highly disaggregated, based on the premise that cities are driven by bottom up processes (Batty, 2005).

Iacono *et al.* (2008) identified three broad approaches to urban modelling namely, spatial interaction models (pre-Lee, 1973 era); econometric models (1980s and 1990s); and microsimulation, agent-based and cell-based models (2000 onwards). Spatial interaction approaches, also referred to as Lowry-tradition or gravity-based models, and econometric models are considered "top-down" approaches – interactions are specified as a set of aggregate relationships based on the behaviour of a representative individual, usually the mean calculated from a representative sample of the population. The vast majority of current operational models used in planning practice follow these approaches (Iacono *et al.*, 2008). Spatial interaction approaches use gravity theory to allocate households and workers in closest proximity to highest concentrations of workplace. There is no representation of land markets with explicit prices.

Econometric models are grounded in land market economic theory and can be either input-output or microeconomics-based. A more recent trend is the development of urban models within a microsimulation framework, which attempt to disaggregate population and simulate changes from the bottom-up, including activity-based travel and multi-agent models and a special type of multi-agent model, cell-based models. "Micro" relates mainly to disaggregation while "simulation" refers to modelling a system as a dynamic and/or complex system, whose behaviour must be explicitly modelled over time. Cell-based models, particularly those based on cellular automata theory can be considered an extension of agent-based microsimulation models in which individual cells act as the agents rather than individuals or households (Iacono *et al.*, 2008).

Rule-based allocation approaches, are not usually found in formal urban model classifications, with Pettit *et al.* (2013) referring to them more broadly as planning support systems (PSS). Rule-based allocation approaches distribute an independent dwelling projection for an urban region to small geographical zones by mimicking the land development process. Allocation is based on an estimate of each zone's

probability of development in each projection interval, which is often assumed to be influenced by factors such as amount of available land; zonings; distance from employment nodes; transportation availability; and access to schools. Such rule-based approaches may have a useful role in making models more accessible to planners and other key stakeholders who can interact with them in real-time, making them more readily able to support a deliberative planning approach. There is a risk, however, that users could interpret the models as being more behavioural than their rules actually are (Waddell & Ulfarsson, 2004).

Two broad sets of issues have been prominent in the literature and in practice in the last decade: incorporating behavioural responsiveness in the internal functionality of models and enhancing the interactiveness between models and external users. The dilemma is that attempts to improve behavioural responsiveness have resulted in more complicated, detailed and difficult models, making them more difficult for users to interact with. Reverting to simpler models, with greater user interaction potential, however, negates what is now known about the importance of behaviour change in city formation (Batty, 2015, p. 192). Batty (2015, p. 192) calls for 'a major trade-off to be made between more aggregate traditional models that are easier to use and much more routine versus these more elaborate and detailed ones which are much harder to build and whose data and computational needs always stretch the limits of what is available and possible' and which are 'much harder to validate' and we would add, much harder to interact with.

Purpose

Two types of urban growth modelling approaches, each applied in two different Australian cities, are considered in this paper. The first, an application of the more complex detailed, agent-based model, *UrbanSim*, in Logan, Queensland (Qld) and the second, the more simple, rule-based model, *Online What-if?*, applied in the North-West subregion of Perth. The purpose of this paper is to assess these case study applications against an evaluation framework developed from a set of best practice modelling criteria as sourced from the international literature. These contrasting approaches are considered in terms of their performance in incorporating behaviour in relation to both internal model functionality and in terms of responsiveness to and interaction with the external user environment. Insights are offered into the trade-offs made in practice and what the learning is in relation to reconciling seemingly competing objectives of simplicity for better interaction with external users and complexity for better responsiveness to changing policy and behavioural responsiveness.

Method

Recent advances in urban growth modelling have been extracted from international literature and form the basis of our evaluation framework. The evaluation framework is used for assessing the performance of two case studies and proposing enhancement in relation to best practice, particularly in relation to the trade-off between more simple approaches, with less internal behavioural rigour but with better potential for incorporating interaction with external users and the more complex approaches, with enhanced internal treatment of behaviour.

A reasonably consistent set of current challenges for urban modelling have been identified and used to review and compare various modelling systems, setting a benchmark for performance evaluation (Waddell & Ulfarsson, 2004; Wegener, 2004; Hunt *et al.*, 2005; Iacono *et al.*, 2008; Waddell, 2011). To a greater or lesser extent, all can be considered under the umbrella criteria of improving the incorporation of human behaviour in the model. For the purpose of this paper, the evaluation framework consists of criteria broadly grouped into those that relate to the internal functionality of the model and those that concern the external user environment – the interaction between models and users in relation both to requirements of the model – what it must do and test – and interaction with the model and its outputs.

Evaluation Framework

Internal model functionality

Behavioural theory based

To evaluate the effects of more complex urban policies including infrastructure demand management initiatives aimed at changing behaviour, urban models with a strong grounding in land market economic theory, dominate recent international best practice trends. A range of spatial processes importantly, land development, location choices of households and businesses and travel should be incorporated (Hunt *et al.*, 2005). Referred to as 'behavioural validity' (Waddell, 2011) or 'comprehensive[ness]' (Hunt *et al.*, 2005), the ability of a model to capture market demand–supply interactions, simulating the behaviour of agents in the land development process, with explicit market prices determined endogenously, is considered critical in assessing a model's capability (Hunt *et al.*, 2005; Iacona *et al.*, 2008; Waddell, 2011).

Land use-transport feedbacks

Whilst the process of land use models providing aggregate of activity-based population and employment inputs to transport models is well established in practice, the feedback from transport to influence the urban activity system is less well done, if at all (Nicolai & Nagel, 2012). Best practice approaches have well established feedback mechanism to influence land use choices through accessibility/composite utility values either in a fully integrated or connected manner (Hunt *et al.*, 2005; Ortúzar & Willumsen, 2011). Land use-transport integration is important so that interactions between transport network performance and land development/location choice behaviour are captured within the model system (Hunt *et al.*, 2005).

Level of disaggregation

As computing power, data availability and data synthesis methods have improved, best practice trends are clearly toward more disaggregated urban models in terms of spatial resolution (number of zones, zone size) and number and classes of agents and activities included. The main benefits of more disaggregated approaches are minimisation of model bias, maximisation of model statistical efficiency, improved policy sensitivity and improved model transferability (Miller, 2003).

The well-recognised trade-off that has to be made with increased levels of disaggregation is that of greater data requirements and this is noted as a significant challenge and barrier to best practice model adoption. In recognition of this, advances in data synthesis methods are often reported in the literature alongside trends in microsimulation. Synthesis is the process of generating data for disaggregated, individual units or agents (e.g. households) from available aggregate data (e.g. census data), usually using some form of Monte Carlo simulation (Miller, 2003).

Uncertainty in long term forecasting

The further into the future the modelling horizon, the more uncertain the outcome. This aspect is becoming increasingly important in risk assessments of alternative policy choices or infrastructure investment. Most existing modelling approaches in practice assume static equilibrium in the forecast year, by adjusting demand and supply elements until demand equals supply, with model end state being path independent, not requiring solution for intermediate years (although intermediate year results can be generated in most cases). With more recent advances in microsimulation there is now enhanced ability of land use models to model land use patterns into the longer term future where behaviour must be explicitly modelled over time, through the processes of path dependency and 'updating' with future system state dependent on current system state and explicitly on how the system evolves from the current state over time (Miller, 2003; Waddell, 2010).

Calibration and validation

Behavioural validity is to no avail in a model unless there is concurrent with 'empirical validity' with predictions corresponding reasonably well to observed reality i.e. results are credible (Waddell, 2010, p. 214). Calibration and validation have been described as 'formidable tasks' due to escalating resource

requirements necessitated by expanding scope and complexity of models, despite advances in computer processing power and data storage (Iacono *et al.*, 2008; Batty, 2015).

Interaction with external user environment

Responsiveness to policy shifts

The ability of models to be flexible in responding to shifts to a more complex, nuanced and demand-management policy environment has been recognised as an important challenge in model development (Waddell & Ulfarsson, 2004). The ability of models to test and evaluate demand management policies and their interactions including travel demand management policies, such as congestion pricing and land-use policies, such as urban growth boundaries, is becoming more important. In addition, greater complexity must be addressed in the form of more infrastructure alternatives available e.g. distributed/off-grid utility and multi-modal transport systems including non-motorised and transit modes and also housing transactions as determined by key actors in the housing market.

Facilitating collaborative planning

Transparency, ease of use and communication are key in using and interacting with models. Collaborative planning is an inclusive planning approach which involves multiple actors being empowered to shape the planning process and ultimately the planning strategy which is an important guide to supporting infrastructure investment. A seminal publication by Healey (1997) on collaborative planning changed the discourse in planning theory from planning *for* the community to planning *with* the community. From an urban modelling perspective this saw the arrival of collaborative planning support systems (Klosterman, 1999; Kwartler & Bernard, 2001; Stock *et al.*, 2008; Glackin, 2012). From the perspective of best practice in urban modelling it is critical that such modelling tools can be accessed and used by the multiple actors which contribute to the planning process. In recent times there has been a move to more group decision making urban modelling tools which utilise interactive touch table technology (see for example, Arciniegas *et al.*, 2013 and Sharma *et al.*, 2011).

There is an increasing need to move beyond understanding and representing urban form as two dimensional space (2D). Those urban models that can present three-dimensional (3D) form and also the fourth dimension (4D) time are considered to be best practice. There are a number of models which can either model the city in 3D such as ESRI's CityEngine (<http://www.esri.com/software/cityengine>) and Geocanvas (<http://www.synthicity.com/geocanvas/>) which take into account fine scale temporal dynamics such as the agent based UrbanSim (Waddell, 2002) or the Cellular Automata driven SLEUTH model (Silva & Clarke, 2002). There is currently loose coupling between such 3D and 4D modelling approaches, yet there is a paucity of models which combine the two.

Application of an agent-based model in Logan, Qld

Designed by Paul Waddell of the University of California, UrbanSim is a rapidly evolving agent-based model system that has been under development since 1996 (see Waddell, 2002; Waddell, *et al.*, 2003, 2004, 2010). The model system has been implemented at several locations in the United States (Kakaraparthi & Kockelman, 2009) and more recently in Europe, Asia and Africa (Patterson *et al.*, 2007; Schirmer *et al.*, 2011). It has received a fair bit of attention in the integrated land use-transport modelling community. Its prominence comes primarily from its disaggregated approach. The system is freely available at www.urbansim.org and has been updated and released since 1998.

UrbanSim draws on random utility theory and the urban economics of location behaviour of businesses and households which is embedded within a modelling framework that deals with land market clearing in the distribution of households and businesses by type (Waddell *et al.* 2003, 2004). UrbanSim predicts the evolution of agents and their characteristics over time, using annual steps to predict the movement and location choices of businesses and households, the development activities of developers, and the impacts of governmental policies and infrastructure choices.

The ability to reflect market behaviour is a key feature of UrbanSim, with consumer and supplier choices explicitly represented, as well as the resulting effects on real estate prices. UrbanSim forecasts the type,

scale, location and timing of residential and non-residential development that forms the basis of urban growth projections in most infrastructure plans. A program of research to adapt UrbanSim for Australian planning practice commenced in 2012 and involved a panel of planners and modellers from a single local government (Brits, 2013). A case study in 2013 implemented UrbanSim at a parcel level to analyse urban growth policy scenarios for an area in Logan known as Loganlea (Brits *et al.*, 2014). Using the prevailing land use policy settings (Logan Planning Scheme, 2006) as a baseline scenario, a second scenario was modelled using increased residential development opportunities close to stations based on transit-orientated development (TOD) principles. Return on investment (ROI) was analysed from 2011 to 2041, and it became evident that UrbanSim was useful in highlighting the spatial and temporal consequences of different land use policy settings over the long term (Brits, 2013). An illustration of the model output is included as Figure 1.

Validation is one of the biggest challenges of UrbanSim. Even though there may be correspondence between the model's output and a real-world system, this is not a sufficient condition to conclude that the model is correct. Empirical validity for UrbanSim was pursued by comparing the performance of the model system to data sources that reflect the observed state or actual world conditions the model system was trying to simulate. For validation, a baseline scenario for the years 2007 to 2011 was simulated using ABS 2006 Census data and compared with the observed population from ABS 2011 Census data. The results showed a reasonable correlation between the predicted and observed population.

Participants felt that UrbanSim should be regarded as a basis for reducing uncertainty about the future, from a prior state of unawareness, to one of more limited uncertainty. The purpose of UrbanSim should not be accurate forecasting, which is not attainable, and instead should be used to analyse and reflect on the likely consequences of draft policy options, prior implementation. A novel methodology has been implemented for calibrating the uncertainty in UrbanSim model predictions using a statistical approach known as Bayesian Melding (Sevcikova *et al.*, 2007).

Even with a Graphical User Interface (GUI), UrbanSim is nevertheless considered by users as a "black box". The process of adapting UrbanSim for Logan took one person six months (full time equivalent) and involved data preparation, model estimation, validation, scenario development and forecasting. The person has a combination of planning, GIS and modelling experience. Modelling results were well received, but planners continued to express concerns around the lack of transparency of the model system; the need for a more integrated and transparent process when developing policy scenarios (i.e. assumptions) as input into the model system; and the need to find ways for planners to communicate with confidence model results to stakeholders (e.g. industry and elected representatives). Recognising the substantial barriers that exist in model use by planners and modellers, the study developed a set of modelling requirements to assist with model preparation and confidence building (Brits *et al.*, 2014).

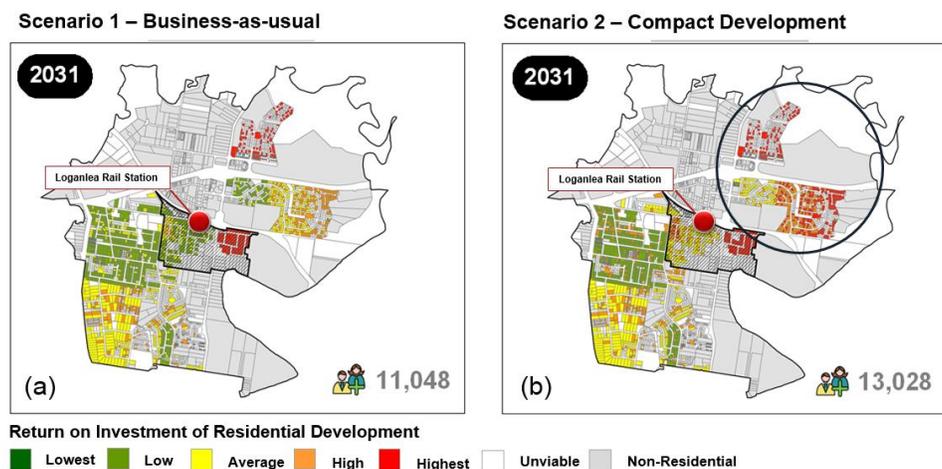


Figure 1: An illustration of the modelling output of an application of UrbanSim in Logan, QLD

Application of a rule-based model in Joondalup/Wanneroo, Perth, WA

The GIS based collaborative What if? planning support system was one of the first PSS tools, developed by Klosterman (1999). The desktop version of What if? has been applied in approximately 30 countries to assist planners in managing land use growth in many different contexts. While the desktop version of What If? is no longer supported, it is freely available via (<http://www.whatifinc.biz/>). However, over the last four years the Australian Urban Research Infrastructure Network (AURIN) has been working with What if?™ Inc. to create an online open source version of the desktop version of What if?, known as the Online What if? (OWI) see: (Pettit *et al.* 2013, 2015). It is this version of What if? that is reported against the evaluate framework developed in this paper; specifically the deployment of the land suitability component of OWI as applied in the Wanneroo and Joondalup municipalities which comprise the North-West sub-region of Perth (Pettit *et al.*, 2015).

The OWI PSS is designed to support policy and decision makers to collaboratively create and explore future land use change scenarios. OWI has land use (i) suitability, (ii) demand and (iii) allocation modules, and is driven fundamentally by demographic population projection. OWI is most suited to supporting land use change scenarios which are based on policies of city growth. This is not a problem in the context of Australia and in-fact the metropolitan area of Perth, which is expecting growth in the vicinity of 600,000 people between 2010 and 2031, as outlined in the Outer Metropolitan Perth and Peel Sub-regional Strategy (State of Western Australia, 2010a). In the context of the Wanneroo and Joondalup OWI land suitability scenarios formulated by Pettit *et al.* (2015), these were used as part of the data informing the Strategic Assessment of the Perth – Peel region, conducted by the State Government in response to the Australian Federal Government Environmental Protection and Biodiversity Conservation (EPBC) Act (Commonwealth of Australia, 1999). Furthermore, these scenarios align with the Perth Metropolitan Planning Strategy known as Directions 2031 (State of Western Australia, 2010b). So OWI is considered a policy responsive PSS which in the context of the Wanneroo and Joondalup case study aligned and informed strategic planning practices in Perth.

OWI can be considered a ruled based system which is driven by the best available data. From the perspective of the internal model function it does not factor in individual or actor based interactions and thus does not support the exploration of emergent behaviours. However, it does support bottom up and collaborative planning approaches where end users, being planners and policy-makers, can interact with modelling parameters in real-time and see what the modifications in land suitability weightings might mean for the overall land suitability scenario being investigated. In the context of the Wanneroo and Joondalup case study OWI was used in a number of planning workshops where such suitability factors and weightings were changed to explore alternative land use change scenarios.

The challenge with any urban model/PSS is the ability to deal with uncertainty and provide meaningful future scenarios. OWI is driven by long range population projections and in the context of this Perth case study these have been formulated by the Western Australia Department of Planning, along with the land suitability factors and constraints used to formulate the land suitability scenarios. However, there is no explicit uncertainty functionality built into the models underpinning OWI. Uncertainty analysis can be undertaken through exporting scenario results and running sensitivity analysis in separated GIS software, as was the case in this Perth example (Pettit, 2015).

Also with respect to empirical validity there are no explicit validation models inherent within the OWI system. Empirical validity is handled by keeping the models simple (rule-based) and transparent. There are a series of simple graphic user interfaces (GUIs) which accompany OWI. This includes GUIs that the user accesses for setting up an OWI project and determining the input parameters which go into the system. There are also a series of map and reporting GUIs which the user can access to tweak suitability parameters, view scenarios results via a mapping interface and generate reports that can be downloaded and interrogated further using standard spreadsheet packages.

Overall, OWI is a simple rule based system which endeavours to avoid being a large complex 'black box' model. However, OWI is not driven by fine scale behaviour modelling, which means it is not conducive in exploring the emergent properties of cities as driven by the behaviour of individual or household

decisions. Yet, OWI has been created as an open source project (<http://aurin.org.au/projects/portal-and-infrastructure/what-if/>), so it would be possible to extend this PSS to consider agent based behaviour.



Figure 2: An illustration of the modelling output (future land use allocation up to 2036) of an application of Online What if? in the North-West subregion of Perth, WA

Learnings, observations and recommendations to transition to best practice

Understanding urban system behaviour presents us with a set of challenges, and linking these with appropriate models raises further challenges. It is clear from our experience that this understanding has to develop between urban scientists, model builders and practitioners over time. Using an evaluation framework, this paper assessed the application of two urban growth modelling approaches, the one an agent-based and the other a rule-based model. The evaluation revealed differences in internal model structure, data requirements, user friendliness, transparency and ability to explore emergent urban behaviour emerged.

These differences pose a significant design problem to the external user environment when it comes to model selection. Decisions on model use depends on knowledge of context, type of policy responses pursued and a fundamental understanding of the strengths, weaknesses and requirements of models. Whereas advances in technology has certainly improved the behavioural responsiveness, access and flexibility of models, use and acceptance by the external user environment remains marginal. Model builders need to accept that the role of science in urban policy-making is much more complex and subtle than generating alternative model predictions and expecting decision-makers to act on these.

Instead of attempting to enhance models to become more predictive and responsive to an ever increasing complex world, model builders should consider enhancing their models to help in the process of framing and generating debate. Model results need to stretch the planners' thinking about how the world around them might change and about how future conditions beyond their control might affect the courses of action they must choose today. Using a model will remain for the foreseeable future "an act of faith on the part of model builders and policy analysts alike, on the part of any professional involved in the process of inventing a better future" (Batty, 2015, p. 193).

Given the complexity of interactions and the large range of possible futures and options available to decision-makers, it is hard to see how urban policy analysis can be undertaken without a level of science and modelling support to help make sense of it all. It is likely that the demand for models is set to increase. Some factors that we believe are priority areas that should be pursued to improve choice, access, use, behavioural responsiveness and communication of models include:

- Use of increased data availability: Data availability is improving. Longitudinal surveys, often with qualitative data, are increasingly accessible online. Linking formal and informal data could be a useful way to advance modelling tools to assimilate and assess data as it becomes available. Present modelling processes and systems are rather poorly connected to these activities, making them a lost opportunity.
- Tools for integrating models and data: As modelling methods improve, becoming better understood, and the number of case studies increases, they should become easier and less costly to apply. However, a major barrier is that integrating data from different sources typically requires additional intermediary stages and significant expert input. Adoption of open standards and platforms in urban modelling software, such as OpenMI (<http://www.openmi.org/>) that facilitate construction of complex model and data interactions could greatly facilitate modelling practice.
- Open source models and protocols: Standards, such as CityGML (<http://www.citygml.org/>), can assist the development and sharing of urban models. Similarly open source modelling codes have enabled wider application and analysis of certain phenomena. However, modelling complex urban behaviour requires a new generation of open source tools and data standards to reflect the much wider range of features that need to be considered and analysed – such as people (importantly social equity) the economy, the environment, impact of climate change, and networks of infrastructure.
- Improve communication of results: Modelling often generates complex results, which cannot be just reported as one set of results. One possibility is to communicate results in a summarised form. However, this obscures the relationships between different urban features, which provide the real added value of modelling and analysis. Many breakthroughs in improved visualisation of complex statistical data are now available to mediate between complex model results and acceptance by end users. For example, the display of UrbanSim model results in 3D with the use of GeoCanvas and gaming engines as reported by Stock *et al.* (2008) provide exciting developments. Yet, there still remains the challenge of difficult of interpreting results without a dialogue of explanation.
- The importance of urban experimentation: Understanding urban system behaviour presents us with a set of challenges, and linking this understanding to urban models, and stakeholders in general raises further challenges. Even if models are providing policy relevant results, policy processes are often not set up to ask these questions or adsorb and work with the results. It is clear from our experience that this understanding has to develop further between urban scientists, model builders and practitioners over time. In this regard, the move to more disaggregated, spatial econometrics-microeconomics, dynamic disequilibrium approaches which are driven by human interaction and behaviours within the built environment provides exciting opportunities. Also the use of group decision making apparatus such as map tables offer novel ways to engage the key actors in a deliberative planning approach where models can be made more accessible.
- Training and education: Building ongoing relationships with planning practitioners is essential for the future of urban modelling. This requires that urban modelling becomes routine and embedded within planning practice. This includes training and education of both researchers and planning practitioners with the ultimate goal of moving models into practice. This is a significant area warranting further investigation as planners are not typically taught how to undertake urban modelling or use tools such as UrbanSim and What if? in their educational studies.

Conclusion

In this paper we have provided a critique of the state of play in urban modelling and introduced a framework for evaluating models. We have then applied this framework in the context of two case studies undertaken in Queensland and Western Australia where the UrbanSim and Online What If? tools have been applied respectively. We then reflected on these case studies and provide a series of recommended areas for further inquiry to enhance the transition to best practice. While the more complex UrbanSim application performs better than the more simple, rule-based Online What if? in terms of incorporating behaviour into internal model functionality, both applications performed well in relation to engagement of external users throughout the modelling process. It is thus not necessary to have to make a trade-off between more simple approaches, with less internal behavioural rigour but with better potential for incorporating interaction with external users and the more complex approaches, with enhanced internal treatment of behaviour. As demonstrated in the UrbanSim application, it is possible to achieve enhanced internal model functionality, incorporating behavioural aspects, while still achieving a high level of external user engagement. It is rather a matter of data availability at the requisite level of detail and know-how, which influences the choice of using a more complex versus a simple model. In an era of Smart Cities, big data and more importantly global urbanization it is becoming increasingly important that decisions about the future of our cities are based on the best available data and evidence. Hence we believe urban modelling is needed to help inform and plan for sustainable urban growth.

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