UCL CENTRE FOR ADVANCED SPATIAL ANALYSIS

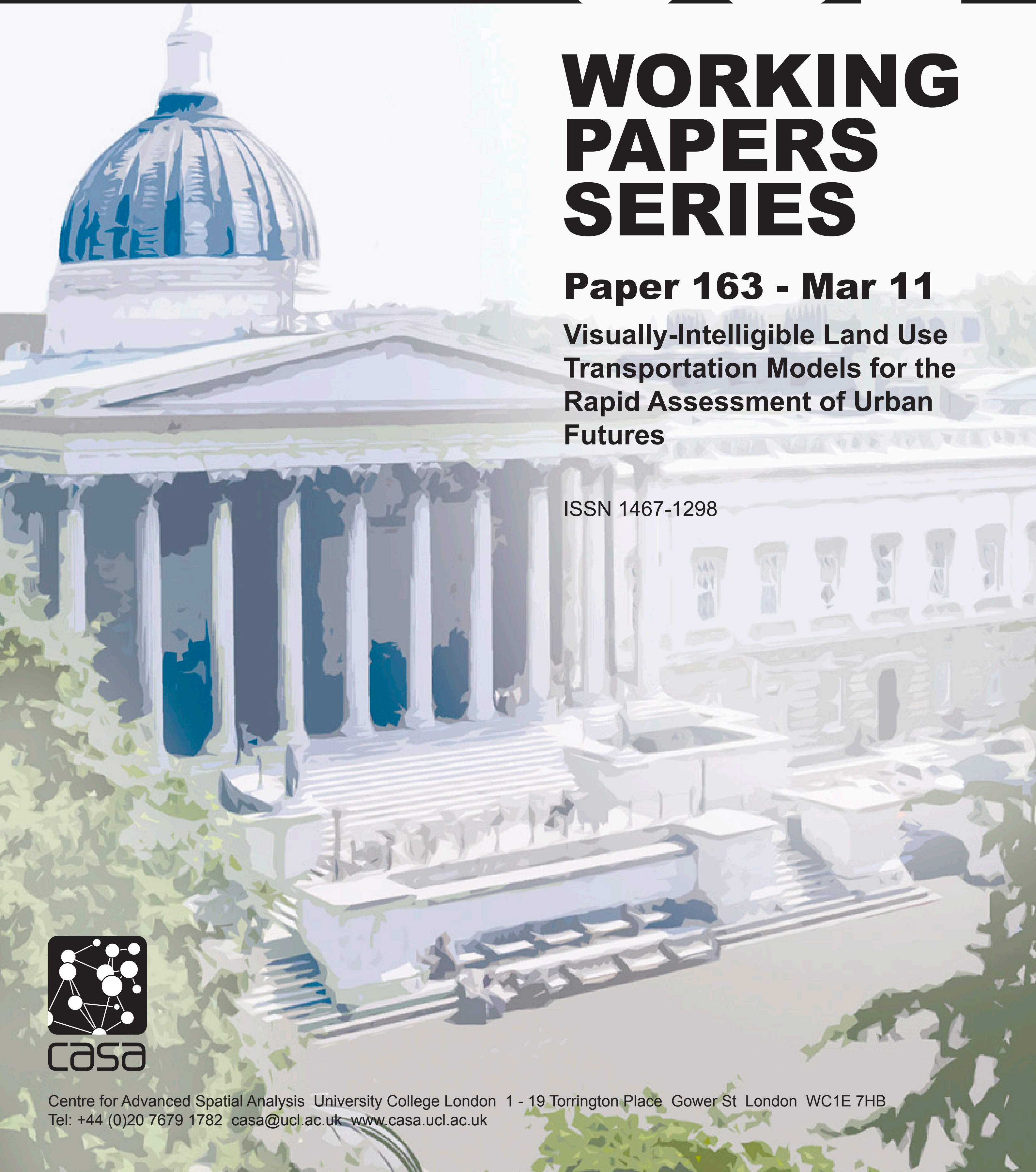
UCL

WORKING PAPERS SERIES

Paper 163 - Mar 11

Visually-Intelligible Land Use Transportation Models for the Rapid Assessment of Urban Futures

ISSN 1467-1298



casa

Centre for Advanced Spatial Analysis University College London 1 - 19 Torrington Place Gower St London WC1E 7HB
Tel: +44 (0)20 7679 1782 casa@ucl.ac.uk www.casa.ucl.ac.uk

Visually-Intelligible Land Use Transportation Models for the Rapid Assessment of Urban Futures

Michael Batty, Camilo Vargas, Duncan Smith, Joan Serras
Jon Reades , and Anders Johansson

5 March 2011

Centre for Advanced Spatial Analysis (CASA)
University College London (UCL)
1-19 Torrington Place, London WC1E 6BT, UK

{m.batty, camilo.ruiz, duncan.a.smith, j.serras, j.reades, a.johansson@ucl.ac.uk}

Abstract

We are building a series of fast, visually accessible cross-sectional, hence static urban models for large metropolitan areas that will enable us to rapidly test many different scenarios pertaining to both short and long term urban futures. We call this framework **SIMULACRA** which is a forum for developing many different model variants which can be finely tuned to different problem contexts and future scenarios. The models are multi-sector, dealing with residential, retail/service and employment location, are highly disaggregate and subject to constraints on land availability and transport capacities. They have an explicit urban economic focus around transport costs, incomes and house prices and thus encapsulate simple market clearing mechanisms. Here we will briefly outline this class of models, paying particular their structure and the way physical flows and locations are mirrored by economic flows in terms of costs and prices. Two versions of the model exist so far. First, a 'one window' desktop pilot version with the simplest imaginable graphical interface, and second a much more elaborated framework developed for web access, extensible to web service architectures and other services. To demonstrate its flexibility and intelligibility, we define the various interfaces and demonstrate how the aggregate model can be calibrated to the wider London region to which it is applied. During the presentation, we will demo the model with respect to the rapid assessment of different urban future based on "What If" scenarios. The key feature of this entire project is that the model and its variants can be run in a matter of seconds, thus entirely changing the traditional dialogue associated with its use and experimentation.

EARLY HISTORY, INTERFACES, STAKEHOLDER REQUIREMENTS

The original genus of land use transportation models emerged in the early 1960s hard on the heels of transportation modelling. These models were relatively large scale in terms of their data and computer requirements and stretched the limits of both of these kinds of resources to the point where many early attempts were never completed. The urban system was also articulated as being in equilibrium with the models being comparative static or equilibrium-seeking in the language of those times, notwithstanding the dilemma of simulating systems that were intrinsically dynamic. This tension between statics and dynamics is endemic to the field and has remained at the cutting edge of urban simulation ever since. The field has now bifurcated into two new traditions: into various theoretical dynamics associated with equilibrium models such as those being developed by Wilson (2008) and into more physically-based land development models mirrored around cellular automata and agent-based models (Batty, 2008a). Their comparative static precursors, however, continue to be the most operational and practical urban models, but with much further disaggregation into activity types and the addition of an incremental dynamics to update their static equilibria.

The intrinsic complexity of the earliest models was immediately appreciated and attempts were made even in the first land use transport model developed for the CATS study in the mid-1950s to disseminate this complexity through graphical outputs (Plummer, 2007). SYMAP graphs and maps were popular but until the advent of desktop computers, there was no immediacy and little interaction between model users and builders other than at the level of the occasional demonstration. Rudimentary interactive graphics was explored in the early 1980s through online access to urban models running on mini-computers which by the late 1980s were running on workstations (Batty, 1992) but it was not until the last decade that computers reached the point where truly interactive processing could be developed (Batty, 2008b). During this evolution, our collective view of the role of models in the planning and design of city systems has radically changed. Fifty years ago, there was a sense in which both model-builders and stakeholders regarded models as providing predictions which could be used with some confidence to help figure out the impact of their plans in rather definite ways with a high degree of certainty. This confidence is now widely regarded as having been misplaced and the role of most models is to now inform, steer and focus dialogue (Epstein, 2008), notwithstanding the continuing practical plea for some measure of certainty about the future. Interaction between model-builders and stakeholders has thus become the name of the game and it is in this context, that the models here are being developed.

This modelling effort began in 2007 with the construction of a residential location model for the Greater London Authority (GLA) region which was part of an integrated assessment of climate change, largely sea level rise over the next 100 years. This model is being used to make predictions of future populations by small area which historically have been in many locations with severe flood risk. The model is prefaced by an input-output model which drives employment growth and is tailed by a cellular automata-like urban development model which distributes population (from ward level) to 50 metre grid squares (Dawson et al., 2009). The current model to be presented here extends this model to a much larger region, from the GLA area which was originally modelled for 33 boroughs, then in a full model based on 633 zones (wards), and now for 1767 wards covering a region from Reading in the west to Southend in the east and from Luton in the north to Gatwick-Crawley in the south. Here we will first sketch the framework for these models which we call **SIMULACRA**, outlining the particular model in formal terms, and then illustrating how the model can be extended to embrace a rudimentary structure for the urban economy. We then focus on the visual interactive interface, showing the desktop pilot and then sketching the full version which will ultimately run in a web-based environment. This sets the scene for a summary of the potential applications of the model which can be implemented extremely rapidly as part of a wider process of planning support.

THE SIMULACRA MODELS

Cross-Sectional Structures and Many Sector Models

The key difference between our approach to urban modelling and that which has dominated past practice is that we are no longer building a single model, but a framework in which we can generate many different variants of a generic model structure rather quickly. **SIMULACRA**† is our suite of models that are initially static models, simulating more than one sector of the urban system, but at only one cross-section in time, yet having the clear potential for extension to deal with increments of time which are encapsulated within the assumed equilibrium. The current model deals with four sectors: workplaces defined by employment E_i, residential defined by population P_j, shopping defined by retail employment R_k, and what we define as local industries generated endogenously in the system that we call internal employment M_ℓ. The subscripts j, i, k, ℓ refer to zones of the system that pertain to all $n = 1767$ for each activity.

The model links these four activity types through spatial interactions – the journey from work to home defined by trips T_{ij} linking employment to population, trips S_{jk} from residential areas to shopping centres, and through implicit industrial linkages measured as accessibilities to employment and to commercial activities defined as A_ℓ. These activities are not currently disaggregated in any way but an extension to such classification is obvious and straightforward. The current GLA model that preceded this one is the first in this suite of models based only on the employment and residential sectors but disaggregated into four travel modes. The current model will be so disaggregated in its next version. In all cases, the activity volumes and their interactions are subject to capacity constraints but currently these are only invoked for the residential sector. Extending these to deal with trip volumes is a major task in taking the current model forward but only the most aggregate version will be presented here.

The Current Urban Model

We first simulate the flow of work trips from workplace origins i to residential destinations j using a singly-constrained spatial interaction model defined as

$$T_{ij} = E_i \frac{L_j \exp(-\lambda c_{ij})}{\sum_j L_j \exp(-\lambda c_{ij})} \quad , \quad \text{where} \quad \sum_j T_{ij} = E_i \quad . \qquad (1)$$

† **SIMULACRA** from Baudrillard (1995) can be defined as "copies of things that no longer have an original". Here it is an acronym that unpacks in many ways, one of which is **SIM**ulating **U**rban **L**anduse **A**s **C**ommercial and **R**esidential **A**ctivities.

L_j is the residential land area which acts as an attractor. The working population at j can be predicted by summing equation (1) over i and then scaling this by the activity rate α which converts employment into population as

$$P_j = \alpha \sum_i T_{ij} \quad . \tag{2}$$

Residential population is also subject to a capacity constraint $P_j^{\max}$ which if invoked, that is *if* $P_j > P_j^{\max}$, leads to a cycling of equations (1) and (2) and the introduction of weights in the residential attractor to ensure that these constraints are met. The residential sector is connected to the retail sector using a similar spatial interaction model which simulates the trips between destinations of the population j and origins of retail employment k

$$S_{jk} = \beta P_j \frac{F_k \exp(-\varphi c_{jk})}{\sum_k F_k \exp(-\varphi c_{jk})} \,, \quad \text{where} \quad \sum_k S_{jk} = \beta P_j \quad . \tag{3}$$

F_k is retail floorspace in k and β is a population-serving ratio which converts population to the demand for retail jobs. S_{jk} is in fact the spatial demand for retail jobs rather than shopping trips but suitable conversion factors can be employed, albeit at a rather crude aggregate level. Retail employment is thus predicted as

$$R_k = \sum_j S_{jk} \quad . \tag{4}$$

Internal employment M_ℓ which forms the local industry sector is predicted using a rather different type of model, more akin to those developed by Putnam (1983) amongst others. This model can be stated as

$$M_\ell = MK \left\{ \gamma \frac{O_\ell}{\sum_z O_z} + (1-\gamma) \frac{A_\ell}{\sum_z A_z} + \right\} \quad \text{where} \quad \sum_\ell M_\ell = M \quad , \tag{5}$$

and the constant of proportionality K is defined so that total internal employment M is conserved. O_ℓ is the total floorspace associated with all commercial/office employment including retail floorspace and A_ℓ is the accessibility to total floorspace Φ_ℓ associated with all employment, which in turn is defined as

$$A_\ell = \Phi_j \exp(-\eta c_{\ell j}) \quad . \tag{6}$$

In equations (1) to (6), the parameters $\lambda, \varphi, \gamma, \eta$ have obvious meanings and are estimated to ensure dimensional consistency and maximise the goodness of fit.

The causal chain from total employment to population to retail and then internal employment is the one first developed by Lowry (1964) but there are many ways in which these three submodels – equations (1)-(2), (3)-(4) and (5)-(6) – can be stitched together and balanced through iteration. In fact the model we are working with solves the equations once in the order given with predicted population being the driving force for retailing. These questions can also be solved as three separate submodels but some modest coupling is useful as this ensures that the predictive power of the model is potentially greater than three individual models. Of course total employment is also predicted from the model as $E_i' = X_i + M_i + R_i$ and this can form the driver for an iterative loop from equations (1) to (6). The equations can also be solved in any order and if constraints are invoked, these can be resolved either through an inner iteration or as part of the outer activities balancing loop. These many possibilities have never been explored in models of this kind, largely because computer resources were not available when these models were first devised and their subsequent history of ever more disaggregation has meant that their aggregate equivalents have not been thoroughly explored. We will not do this here but it is an essential goal of the wider project.

One last point. Two of these three models – the residential and retail location models – are similar in structure. That each simulates a rather different process suggests that they should be sufficiently different to capture the salient elements of their respective subsystems. This we refer to as Wegener's (2008) principle which is based on his plausible argument that as retailing is a rapid response activity, the spatial interaction model used here is appropriate whereas the residential location model is not largely because housing costs and budgets are not factored into the model The model dealing with internal employment is appropriate in that it contains factors dealing with land supply in terms of floorspace. To meet his critique, we can extend this model to deal with the local urban economy and to this end, we will digress into a parallel formulation which leads to a more appropriate residential location model.

ADDING THE URBAN ECONOMY

Incomes, House Prices and Travel Costs

It is possible to consider flows of people in this model as flows of money. Wages are earned at employment locations and money is spent on travel from work to home and then on housing at the residential end of such a trip. Consumer goods are generated by the population, purchased at the retail end of the trip and consumed at the residential origin. Here our model will not embrace consumer spending on retail goods but simply consider monies spent on housing which we will meld into a form which leads to a more appropriate residential location model for which we have the requisite data. We have income per head y_j and also average house price ρ_j at place of residence j but we do not have wages w_i per head or in total W_i at places of employment. Noting however that we have flows of workers, trips T_{ij}, the money flow from i to j

can thus be calculated as $T_{ij} y_j$ where we can work out both total wages W_i and total income Y_j at the household end as

$$\sum_j T_{ij} y_j = W_i \quad \text{and} \quad \sum_i T_{ij} y_j = \alpha^{-1} P_j y_j = Y_j \qquad . \tag{7}$$

It is thus easy to show that

$$\sum_i W_i = W = \sum_j Y_j = Y \qquad , \tag{8}$$

where Y is total income in the system, balancing with total wages W at all times.

We need to link wages and incomes to the total spent on transport and housing. At the household end, we have good data on the spending in these categories by income y_j and from these we are able to derive excellent regression models that enable us to generate monies spent on housing h_j and monies spent on travel c_j [‡]. We can then factor back in the same way and generate monies spent on housing and transport at employment locations i. To balance budgets, we need to ensure that average house prices ρ_j and travel costs c_{ij} sum to the total monies Π and T available and thus we must ensure that

$$\sum_i E_i h_i = \Pi = \sum_i \sum_j T_{ij} \rho_j = \sum \alpha^{-1} P_j h_j \qquad \text{and} \tag{9}$$

$$\sum_i E_i t_i = T = \sum_i \sum_j T_{ij} c_{ij} = C = \sum \alpha^{-1} P_j t_j \qquad . \tag{10}$$

We are now in a position to formulate the new model.

3.2 The Residential Location Model

The model is based on the idea that workers have monies to spend on housing and transport which varies according to the wages they receive at their place of work. This conditions the probability of their journeying to some different location to live, the assumption being that the smaller the difference between their available monies for transport and housing and the cost of travel to that place and the cost of housing there, the greater the probability that they will locate there. This replaces the classic negative exponential travel cost function. Strictly we can formulate the constraint associated with travel as a difference or variance σ^2 between these two sets of costs. Then, the system must satisfy the constraint

$$\sum_i \sum_j T_{ij} [(h_i + t_i) - (c_{ij} + \rho_j)]^2 = \sigma^2 \qquad . \tag{11}$$

[‡] We estimate $t_j = -134.81 + 0.388 y_j, r^2 = 0.99$, $h_j = 67.50X + 0.029\, y_j, r^2 = 0.60$, and then $t_i = -134.81 + 0.3877(\Sigma_j T_{ij} y_j / E_i)$, $h_i = 67.503X + 0.0294(\Sigma_j T_{ij} y_j / E_i)$.

The model that is generated from this constraint and which is the alternative residential location model in the current model variant is

$$T_{ij} = E_i \frac{A_j \exp(-\lambda[(h_i + t_i) - (c_{ij} + \rho_j)]^2}{\sum_j A_j \exp(-\lambda[(h_i + t_i) - (c_{ij} + \rho_j)]^2} \quad , \qquad (12)$$

which is subject to the usual origin constraint, generating population from equation (2) with (12) replacing equation (1).

One word about calibrating the model structure in equations (1) to (6) with either the residential model based on equation (1) or (12). Essentially the parameters λ, φ, η relate to constraints on travel costs or variances which are consistent with their derivation using entropy maximising or maximum likelihood. These can be approximated from continuous equivalents of the submodels but strictly some iterative scheme is required because the models are coupled and because the parameter γ is not related to any formal constraint equation. In this paper, we will not explore this calibration process in any detail other than to note it because our focus is more on the framework and its interface to the planning support system that sustains it.

VISUAL TEMPLATES

The Desktop Model

Our previous residential location model for the 633 zones comprising the GLA metro region was configured as a visually accessible interactive desktop application. The users can interrogate this model at every stage from the initial stage of data exploration and analysis, through calibration and thence into evaluating predicted impacts on location and interaction as part of a wider set of ‘What If’ style scenarios. This model is based on multiple windows being launched in a systematic way through a toolbar sequence that drives the model input-calibration-prediction processes. In this version of the model, we decided to construct a much simpler desktop pilot which essentially is configured within ‘one window’ which in turn is divided into different frames. This simpler interface makes the model much faster to run and the data input or predictions are much easier to explore and comprehend. We decided to develop this in parallel to a more elaborate version built generically in state of the art software. This will be the main workhorse here as we begin to disaggregate activities and interactions and extend the number of activity sectors that the model will deal with.

The ‘one window’ desktop version is driven from a simple toolbar which contains the key buttons controlling the sequence of stages. The main frame contains a map window while other frames relate to model settings, parameter values, and model outputs. Despite the fact that as much information is packed onto the screen as possible, various numerical outputs are routinely produced for offline analysis. The screen is thus organised in one window with the various frames configured in this window as we show in Figure 1. Model functions form the commands that drive the modelling process, while once the data is read in and normalised, activity totals for the region as well as the zonal map are displayed to give the user some immediate sense of the scale of the region. Parameter values for the three models are then fixed using sliders whose default values are $\lambda = 2/\overline{C}$, $\varphi = \eta = 2/\overline{S}$, and $\gamma = 0.5$ where $\overline{C}$ and $\overline{S}$ are the mean trip travel costs[±] and γ is the parameter moderating the weight of floorspace supply and accessibility in the simulation of internal employment. These can be varied by the user but once fixed, the model is run, constraints invoked if required, and then the goodness of fit statistics are computed. These are displayed in appropriate panels.

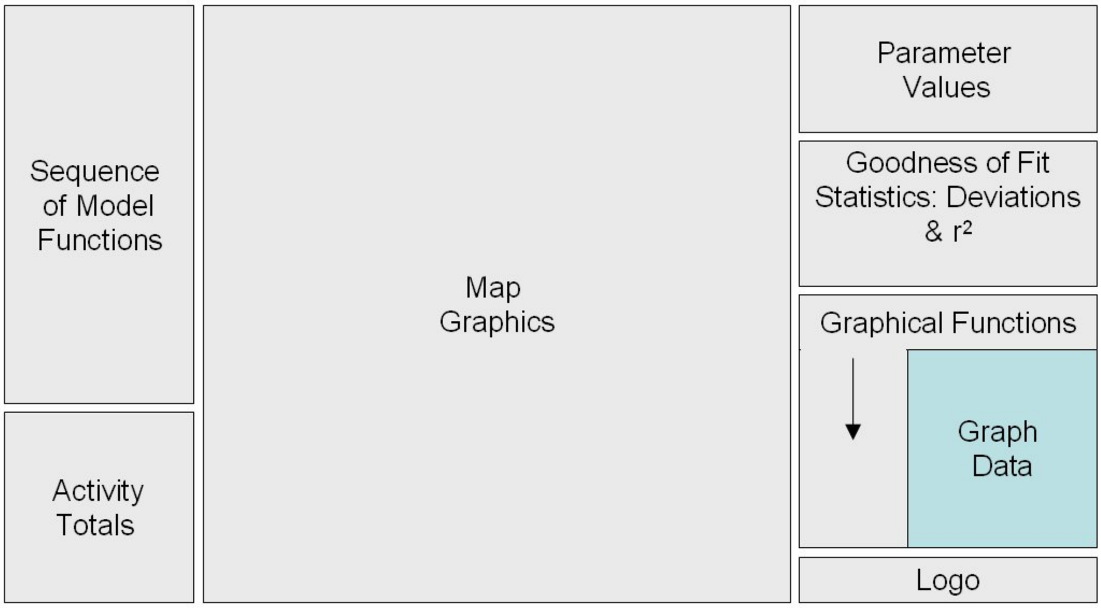


Figure 1: Organisation of the 'One Window' Desktop Pilot Interface

The user is then invited to explore the predictions through a series of graphic functions enabling activity count and/or density data to be mapped in thematic or histogram form. Deviations between observed and predicted activities can also be explored in map form with the user launching each choice of map sequentially within the map window. Figure 2 provides a typical example of the process at the point where the model has been run and goodness of fits produced. The user is also informed of the time taken to run each stage of the model as it completes. The fastest we have been able to run the model in Figure 2 is 6 seconds on a PC 64Bit 3.07GHz with the overall process taking some 25 seconds. This is comparable to running the model under Virtual Fusion on an iMac with 3.2 GHz which gives 7 and 29 seconds. On the **Vaio VGN-SZ** 1.32 GHz laptop used to demonstrate the model in this lecture it takes 24 seconds for a model run and 90 seconds overall. For a model with 1767 zones, this is orders of magnitude faster than anything we have come across hitherto, notwithstanding the dearth of experience in running these styles of aggregate models in recent years.

± $\overline{C} = \Sigma_i \Sigma_j T_{ij} c_{ij} / \Sigma_i \Sigma_j T_{ij}$ and $\overline{S} = \Sigma_j \Sigma_k S_{jk} c_{jk} / \Sigma_j \Sigma_k S_{jk}$.

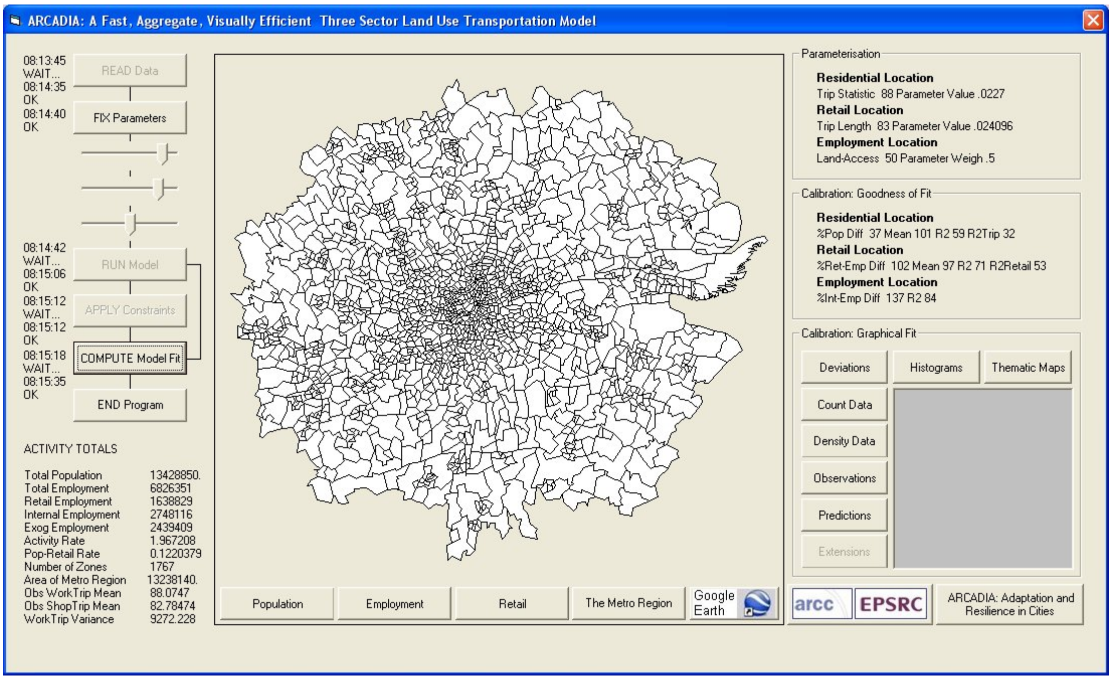


Figure 2: A Complete Run of the Desktop Pilot Model

This model has been run on a slow PC laptop, the one used to present this paper and to demo the model at the Conference

The Web-Based Model Interface

We have not yet constructed this interface in any complete sense although just as there are links from the desktop pilot to the display of outputs in **Google Earth** as the model is running, the same sorts of links are being made within the full model which currently is still in desktop form although considerably more generalised. The full model is written in a very different way as a set of fully extendable Java-based software components. The system is designed to integrate various open source tools and we have made extensive use of object oriented technologies to implement a general framework and data exchange environment. This enables us to embed common subsystems like GIS, various simulation models, management tools, databases and other external data sources in the framework. The basic design principles follow client-server architecture, based on a Multi-Tier style in which the components related to the user interface, the functional process logic and the data storage are maintained as independent modules or tiers. Through the separation of the components into different tiers, the solution allows any of the modules to be upgraded or replaced independently as requirements change without affecting other modules. Figure 3 defines an initial three tiers whose main components are the multi-dimensional data warehouse at the bottom, the application tier above this written in Java which controls the specific application functionality for running the land use transportation model, and the presentation tier which is designed as a RCP (Rich Client Platform) application for desktop environments and a RIA (Rich Internet Application) for web environments. The object oriented domain model is the set of classes that represents the entities which define the structure of the actual data and perform the associated modelling processes. This is formulated as a series of classes that we do not have time to detail here but essentially involve the main *LUTiModel* class; this entity represents the core element of the **SIMULACRA** domain model which is decomposed into two core classes, the *DataAdministrator* and *ModelAdministrator* classes which control all data and model functions respectively. Currently we envisage the need for complete flexibility in the zoning systems to which these models are to be applied and thus we treat each zone as a class called *Zone* which enables us to perform different kind of operations to store, process or display the set of zones and their related information for the particular city or region that we wish to represent. In short, the structure is designed so that we can apply it to any area for which we can define distinct zones and their data.

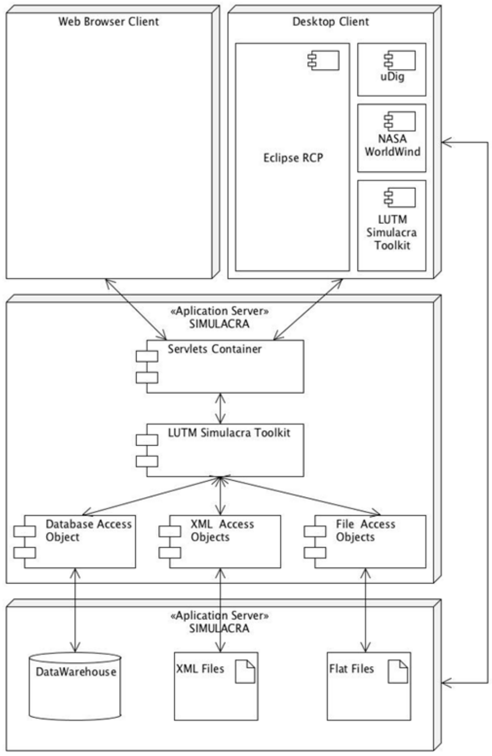


Figure 3: The Three Tier Architecture for the Full (RCP-RIA) Model

To represent this type of complex behavior for storing, processing or displaying the information, we have designed the solution based on the Java bridge pattern which separates the representation of the set of zones from its specific implementation. By using the bridge pattern with two separate inheritance-matching elements from the user interface and the data storage, we provide greater flexibility at a lower coding cost. Following the same principle of the bridge pattern the *DataAdministrator* class defines the functional abstraction, the *IZoneInteractionContainer* interface represents the specific functionality used by the *DataAdministrator* instances and the *ZoneInteractionContainerImplA* provides the behavior and structure for the *IZoneInteractionContainer* classes. Originally, the relationship of the *ModelAdministrator* to *ResidentialModelA*, *RetailModelA*, *EmploymentModelA* was one-to-one. However, due to the rapid evolution of each sub model as we illustrated in the desktop pilot, we have implemented a bridge pattern for each one of the sub-models. It is worth noting that the submodels defined here are special implementations of a more general class of spatial interaction model which follows the typical family of such models based on different kinds of constraint (Senior, 1979).

The core philosophy of the main **SIMULACRA** GUI (graphical user interface) is usability based on interactivity, learnability, flexibility and robustness. In this context, during the design process of the GUI, the RCP (Rich Client Platform) has assumed a continuing importance in enabling us to use a set of open source components, each fulfilling a particular functional role: these are the **Eclipse** RCP, **UDig**, and NASA **World Wind**. The **Eclipse** RCP provides high performance cross-platform Java user interface libraries, an advanced plug-in framework for integrating third party code, and a very large user community and testing framework. GIS functionalities are provided by **uDig** where maps are a central component of the application as we show below. NASA **World Wind** is a 3D interactive world viewer where we can explore other graphical options for displaying histograms and other map and flow layers that, like the use of **Google Earth** in the desktop pilot, enables us to link to data that is not formally part of the model system. The model run on an ***iMac*** similar to that used to demo the desktop pilot takes 7 seconds.

CALIBRATION, PREDICTIONS, APPLICATIONS

Fitting the Model

The desktop and RCP-RIA models are currently coordinated, reproducing the same outputs and we will report preliminary results. Table 1 presents parameter values, deviation statistics, and coefficients of variation for the three submodels decoupled from one another and for the house-price-travel cost variant of the residential location model, sketched out above. The models have been calibrated by trial and error but we know the results shown can be massively improved once the models are better tuned to the data and formulated with their appropriate constraints. Nevertheless for the standard three submodels the results are acceptable. The residential submodel does not perform as well as the other two and when we use the price-cost variant, this performance deteriorates further. We are currently exploring this model formulation offline through extensive data analysis of costs and prices in the region, and we intend to produce a much more realistic specification once we have identified the appropriate trip making behaviour with respect to these costs.

Table 1: Goodness of Fit to the Base Year (2006) Calibration

Location Model	Residential	Residential Price-Cost	Retail	Internal Employment
Parameter	0.268	0.0001	0.278	0.278
%Deviations	39	42	104	134
r^2 Locations	0.55	0.61	0.68	0.84
r^2 Interactions	0.34	0.10	0.55	Na

In Figure 4, we show several map variants with respect to the performance of the desktop pilot where we plot a sample of outputs based on deviations between observed and predicted counts and densities, histograms of counts and densities, and standard thematic maps. The key point to note is the speed at which these model runs and plots can be presented; in essence, the desktop model is suitable for use within a normal process of stakeholder dialogue where users and model builders can cluster around the model and explore many, many variants in a matter of hours, enabling rapid feedback concerning model results and the impacts of different scenarios. In Figure 5, we show similar outputs from the RCP-RIA model where more information is generated in terms of the display. This is akin to the previous 633 zone desktop model that we built for the GLA except that the run and display speeds are considerably faster. For both models, immediacy of response is impressive.

However these models are the simplest possible, too simple perhaps, notwithstanding the fact that there is considerable research still to do on their overall coupling and hence convergence properties. Our intention is to first disaggregate by transport mode as we did in our GLA model (Batty, 2011). This would increase running times by 4 or 5. Each submodel would essentially be replicated for the 4 or 5 modes that are to be made explicit. We then plan disaggregation into at least 5 population and/or house types and we intend to reconfigure the employment sectors so that we have at least five different employment types – currently we have three – retailing, internal employment and exogenous employment. This will probably increase running times by at least 5 again and thus a conservative estimate of the disaggregated model is that it will take at least 25 times as long to run. This means we will need to move to the RCP-RIA framework for most future development although we will continue to mirror the full model with the desktop pilot as long as this remains useful to overall development, demonstration, and dialogue.

Rapid Assessment of Alternative Plans

We have already some experience of using our previous GLA model for such rapid assessment. A comment on our preliminary proposal to present this paper professed "I am wondering how the authors can Rapidly Assess Urban Futures?". In fact we will not demonstrate any results in this paper but we will do so in the meeting itself, a suitably good forum in which to demonstrate the power of the framework. In fact, increasingly urban models of any kind are being ported into contexts where immediacy and visual intelligibility is a key criterion and this can often only be illustrated by hands-on demos. Moreover in the presentation, we will illustrate how we have been evaluating scenarios involving changing energy costs which we have explored extensively in our previous GLA model (Batty, 2011). By the time of the meeting, we may even have an "APP" of this model running on an ***iPad*** which we are currently considering, thus making the model available in contexts within which such tools have never been available hitherto.

The requirement to evaluate scenarios rapidly requires an evaluation function within the modelling framework that has not yet been built but is under construction. Part of this is based on the fact that the model is now underpinned by prices and travel costs. We are extending this to deal with expenditure on consumer goods and we will be building in a land supply component into the various models that reflect rents (as well as house prices which are already a part of the residential location model). Because we are able to simulate the flow of money as well as people within the model, we can assess scenarios that do not only deal with changes to the physical structure of the metropolis in terms of land supply (constraints), transport infrastructure, and changes to the provision of floorspace but also with changes in travel costs, in wages, in house prices and such like. In fact these kinds of model are most appropriate (as indeed are many if not all models) to dealing with 'What If' type scenarios of which we can generate many variants. As the model can be run rapidly and the evaluation of scenarios is immediate, we need to produce a framework for the consistent generation of such scenarios so that we can engage in considered choice of what to test and relate these using appropriate sensitivity analyses. These are features of more general planning support systems that are slowly being exploited despite the somewhat tortuous path to their development (Batty, 2008b).

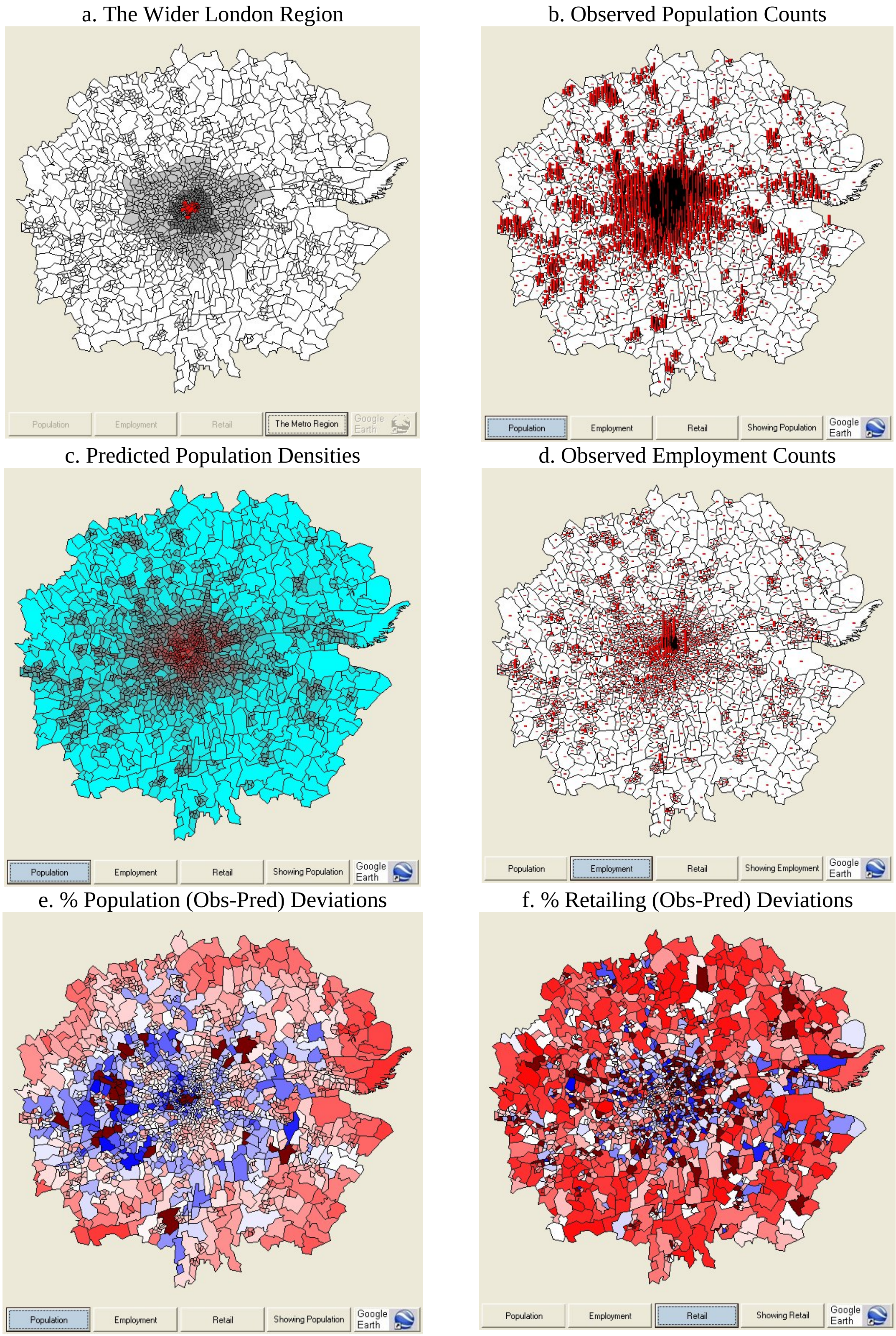


Figure 4: Sample Data and Model Outputs from the Desktop Pilot

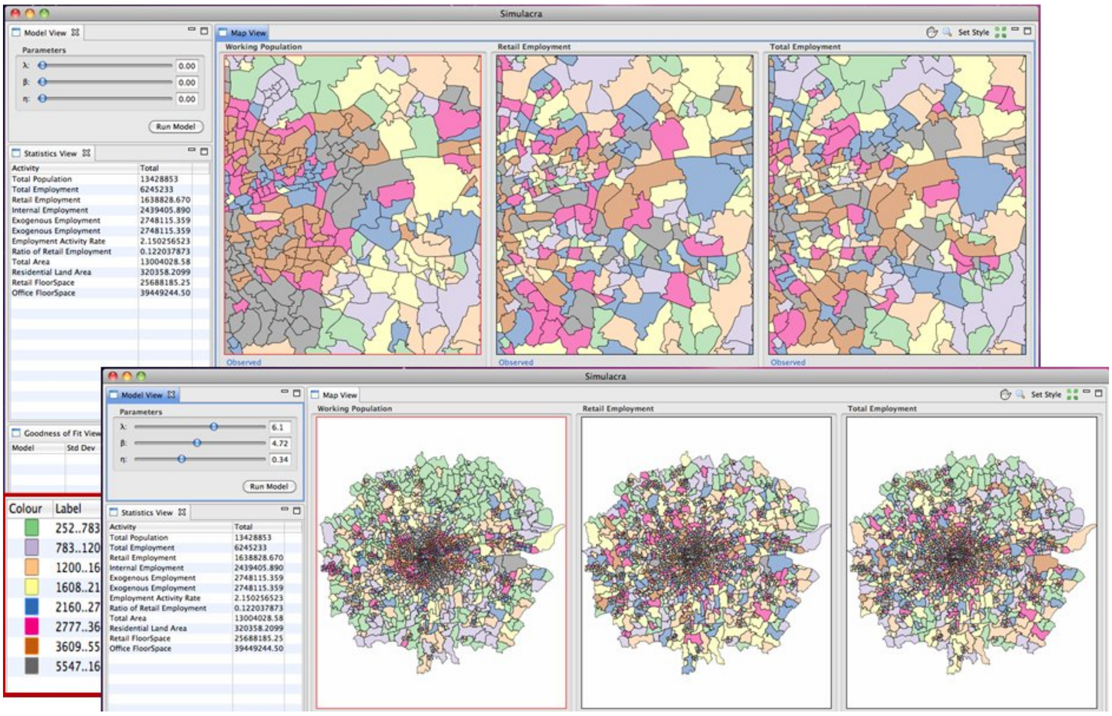


Figure 5: Sample Data and Model Outputs from the Full (RCP-RIA) Model

KEY CHALLENGES, FUTURE DEVELOPMENTS

We have listed the key development trajectory for this suite of models but in conclusion we need to critically explore the extent to which this genus of comparative-static equilibrium models of urban structure provides a path worth following. As we have noted, there are many aspects of such models that have never been explored, particularly their coupling and convergence properties. This, we believe, is worth doing as much because of the light it will shine on coupling models in general and on the perpetuation of errors as on the appropriateness of the particular model structures to be further developed here. These models do not come into their own until they are disaggregated and thus this is a work in progress, as much informing readers about what we intend to do and how we will do it, as reporting work that has already been finished.

However, there are some very important developments in comparative static models of this kind that we intend to pursue. First, these models have an intrinsic dynamic structure in that we can partition activities into movers and stayers, activity that is inert and that which has the potential for change. This has never been done before and it represents a new way of embedding dynamics into model structure. Some hints as to how to do this were given a generation ago by one of the authors (Batty, 1986) but such developments are now possible because we have the power to continually experiment with model structures, something that was quite impossible before the current advances in computation which have essentially abolished or at least dramatically changed the limits on such exploration. Just as the whole process of planning support is being refashioned due to the use of online tools that provide immediate feedback, our ability to explore large, relatively realistic models in a rapid manner is providing a new dimension to this science. In the immediate future, we will develop the **SIMULACRA** models in three ways: first through disaggregation which poses challenges for running time, second through the addition of explicit indicators which can be grafted onto this framework in the manner developed for the Propolis consortium project in 2004 (http://www.ltcon.fi/Propolis/index.htm), and last but not least, the development of an intrinsic internal dynamics to comparative static models that promises to address the obvious concern that cities are never and never will be in equilibrium.

REFERENCES

Batty, M. (1986) Technical Issues in Urban Model Development: A Review of Linear and Non-Linear Model Structures, in B. G. Hutchinson and M. Batty (eds.) **Advances in Urban Systems Modelling**, North Holland Publishing Company, Amsterdam, 133-162.

Batty, M. (1992) Urban Modeling in Computer-Graphic and Geographic Information System Environments, **Environment and Planning B**, Vol **19**, 663-685.

Batty, M. (2008a) Fifty Years of Urban Modelling: Macro Statics to Micro Dynamics, in S. Albeverio, D. Andrey, P. Giordano, and A. Vancheri (eds.) **The Dynamics of Complex Urban Systems: An Interdisciplinary Approach**, Physica-Verlag, Heidelberg, DE, 1-20.

Batty, M. (2008b) Planning Support Systems: Progress, Predictions, and Speculations on the Shape of Things to Come, in R. K. Brail (ed.) **Planning Support Systems for Cities and Regions**, Lincoln Institute of Land Policy, Cambridge, MA, 3-30.

Batty, M. (2011) Dynamics of Land-Use Change and Growth, in D. Robinson (ed.) **Computer Modelling for Sustainable Urban Design: Physical Principles, Methods and Applications**, Earthscan, London, 237-258.

Baudrillard, J. (1981, 1995) **Simulacra and Simulation**, University of Michigan Press, Ann Arbor, MI.

Dawson, R., Hall, J., Barr, S., Batty, M., Bristow, A., Carney, S., Dagoumas, A., Evans, S., Ford, A., Harwatt, H., Kohler, J., Tight, M., Walsh, C., and Zanni, A. (2009) A Blueprint for the Integrated Assessment of Climate Change in Cities, in K. Tang (ed.) **Green Citynomics: The Urban War Against Climate Change**. Greenleaf Publishing, Chippenham, UK, 32-51.

Epstein, J.M. (2008) Why Model? **Journal of Artificial Societies and Social Simulation**, Vol **11**, no. 4, 12, http://jasss.soc.surrey.ac.uk/11/4/12.html

Lowry, I. S. (1964) **A Model of Metropolis**, Memorandum RM-4035-RC, The Rand Corporation, Santa Monica, CA.

Plummer, A. V. (1990) The Chicago Area Transportation Study: Creating The First Plan (1955-1962): A Narrative, dated on web site as of 14-Dec-2007, http://www.catsmpo.com/pub/reports/history/cats_1954-62.pdf

Putnam, S. H. (1983, 2007) **Integrated Urban Models: Analysis of Transportation and Land Use**, Routledge Library Editions, London.

Senior, M. (1979) From Gravity Modelling to Entropy Maximizing: A Pedagogic Guide, **Progress In Human Geography**, Vol **2**, 175-210.

Wegener, M. (2008) Multi-Scale Spatial Models: Linking Macro to Micro, http://www.spiekermann-wegener.de/pro/pdf/MW_CASA_090108.pdf

Wilson, A. G. (2008) Boltzmann, Lotka and Volterra and Spatial Structural Evolution: An Integrated Methodology for Some Dynamical Systems**, Journal of the Royal Society Interface**, Vol **5**, 865-871.