5 June 2013

Smart Cities

Session 4: Lecture 3:
Urban Simulation and Prediction

Michael Batty

m.batty@ucl.ac.uk
@jmichaelbatty

http://www.spatialcomplexcity.info/
http://www.casa.ucl.ac.uk/

Outline

- Models in General and Prediction
- LUTI Models: A Little Bit of History, Early Graphics Interfaces, and the Tyndall Model
- SIMULACRA: ARCADIA and SCALE Projects
- Requirements: The Model Design: Models Flows: Physical Movements, Money & the Employment and Residential Models
- The Visual Template: The Desktop Model: Running It
- Building a Web-Based Model Interface
- Data Bases: Location, Interactions & Networks
- Current Challenges for Immediate Development

Models in General and Prediction

Clearly models of urban structure, digital iconic models, and GIS tools relate to our abstractions of cities – virtual rather than real but how can we relate all this to real cities – i.e. to making cities smart – clearly these are tools to inform design and policy

Digital participation is the key – of course and in some of our models we are beginning slowly to explore this.

Moreover the speed at which these models might be used – the frequency is an issue – we might be able to use them routinely – update them every day and thus compress timescales

Visualisation is key to this, cloud computing and big data: ok more of this as we continue but first some history

LUTI Models: A Little Bit of History

Early models: CATS 1955: The 1960s Models

Largeness, remoteness from users, crude representation, limits on computation, poor links to policy

Lack of understanding of model outcomes

Statics versus dynamics – semi-dynamic models but most operational models predicated in terms of equilibrium and as we have seen, the most developed are structured in terms of a dynamic equilibrium

Disaggregation of sectoral activities

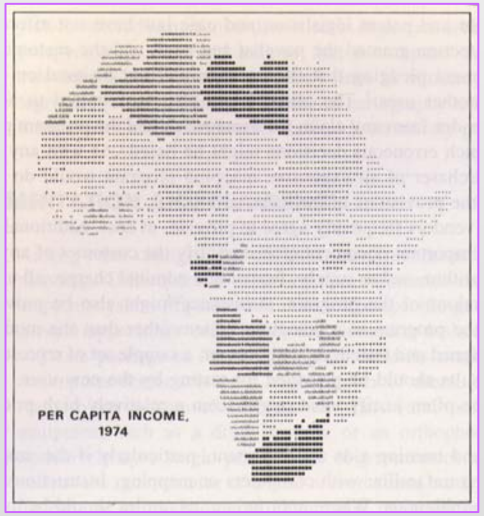
Many aggregates can be treated as agent, many zones

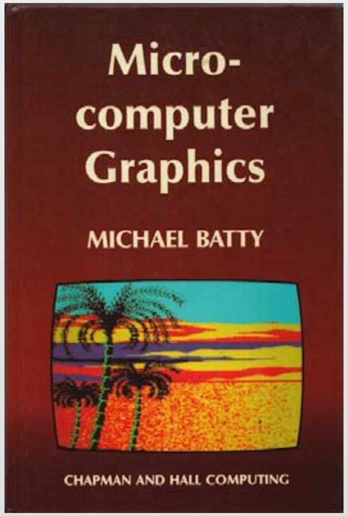
Early attempts at Visualisation: Traffic Flows in CATS, and Schmidt's model of the growth of East Lansing 1967

Harvard Lab: SYMAP – Symbol Mapping Systems, 1967-1970

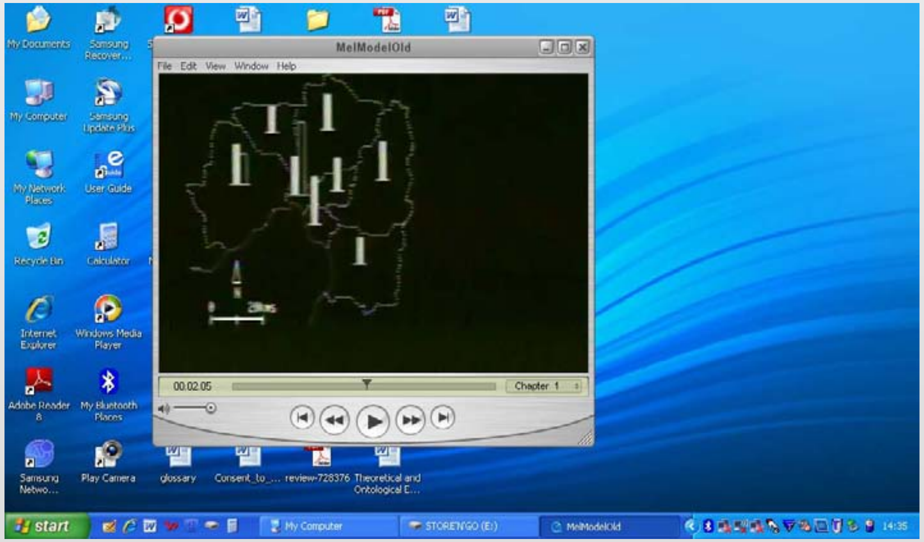
Early cathode ray displays, 1960

Apart from some SYMAP applications, my own attempts began in the early 1980s with the Melbourne Model





- I didn’t work on these models as such from about 1982 onwards as I got into fractal type stuff with Paul (Longley) but I did develop quite a lot of visualisations really for demo and teaching purposes
- Early version of Melbourne model in 1982 and then development of a WATFor77 version in 1986
- The Melbourne Version is primitive and not nice to look at because we attached a video to the raster display device



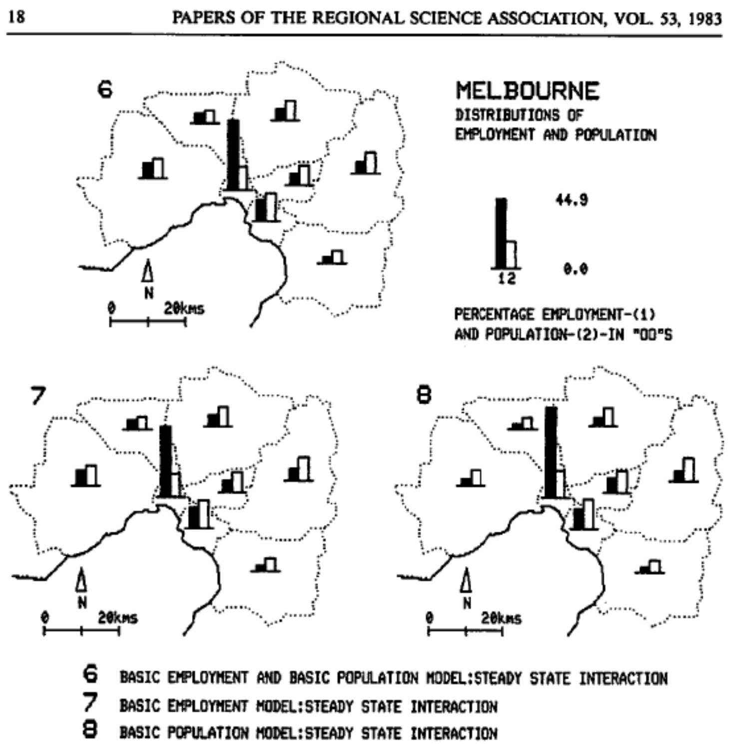


FIGURE 2. Predicted Distributions of Employment and Population for the Models Based on Steady State Interaction Patterns

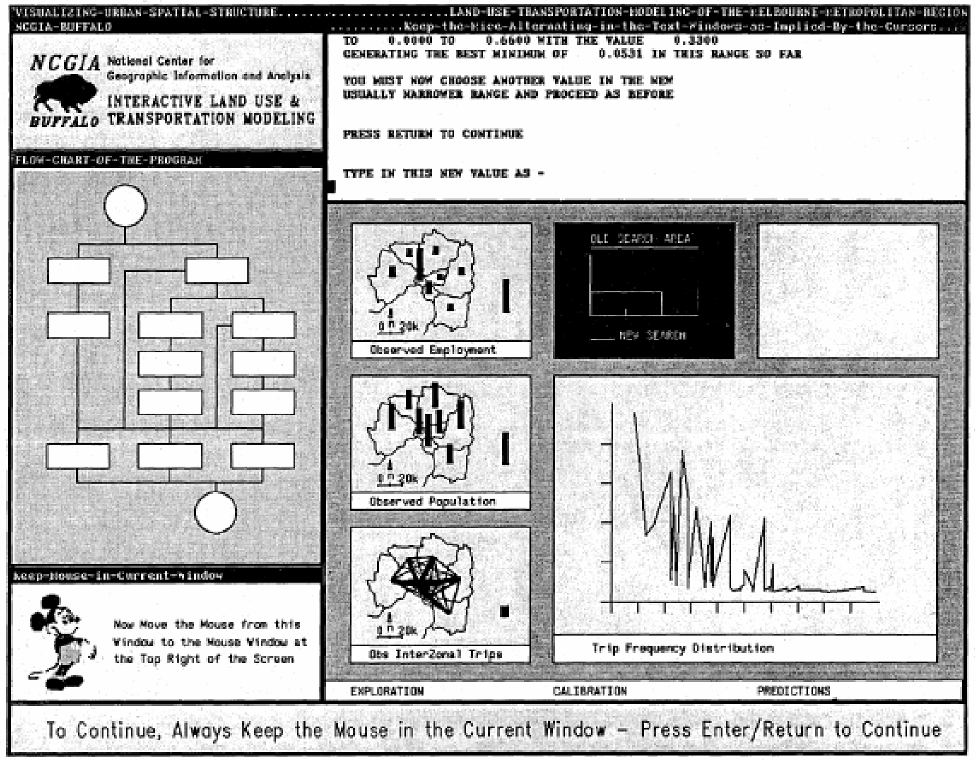


Figure 6. Progress in calibrating the model using dichotomous search.

From a VAX Terminal – A Raster 1982

From a Sun Workstation – Simple Windows - 1991

I don't have time to show the 1986 demo – I showed it at CUPUM in fact in 2009 but it still runs under DOS on this laptop

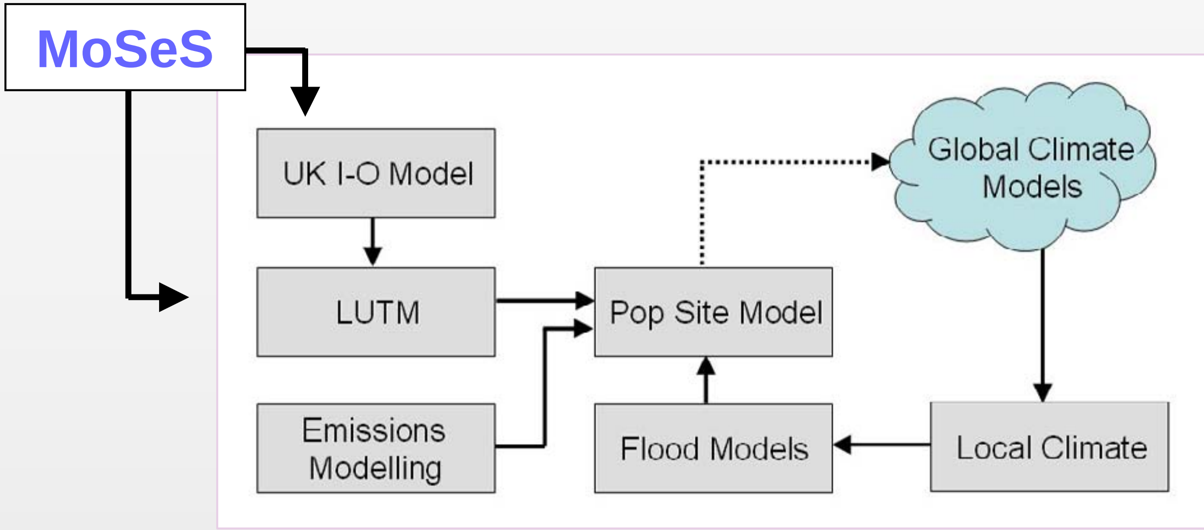
And bringing it all more up to date:

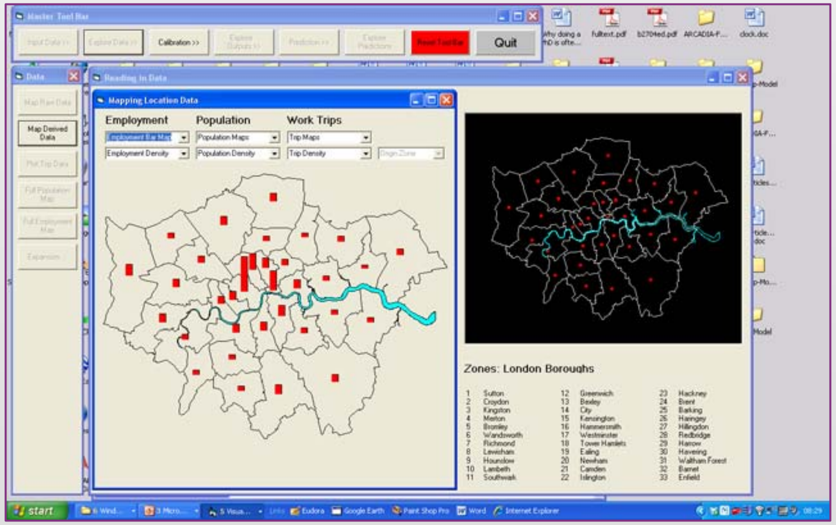
You have seen what we were involved in on the Tyndall Model where one of our guiding principles was to communicate the model as easily and as effectively as possible to our stakeholders

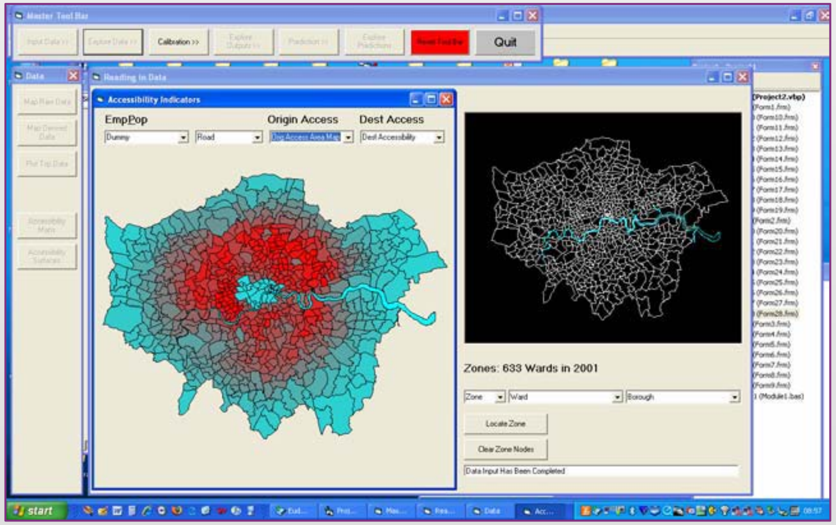
These were largely policy analysts and had some expertise in climate change problems and some knowledge of models of various kinds but not any one particular model

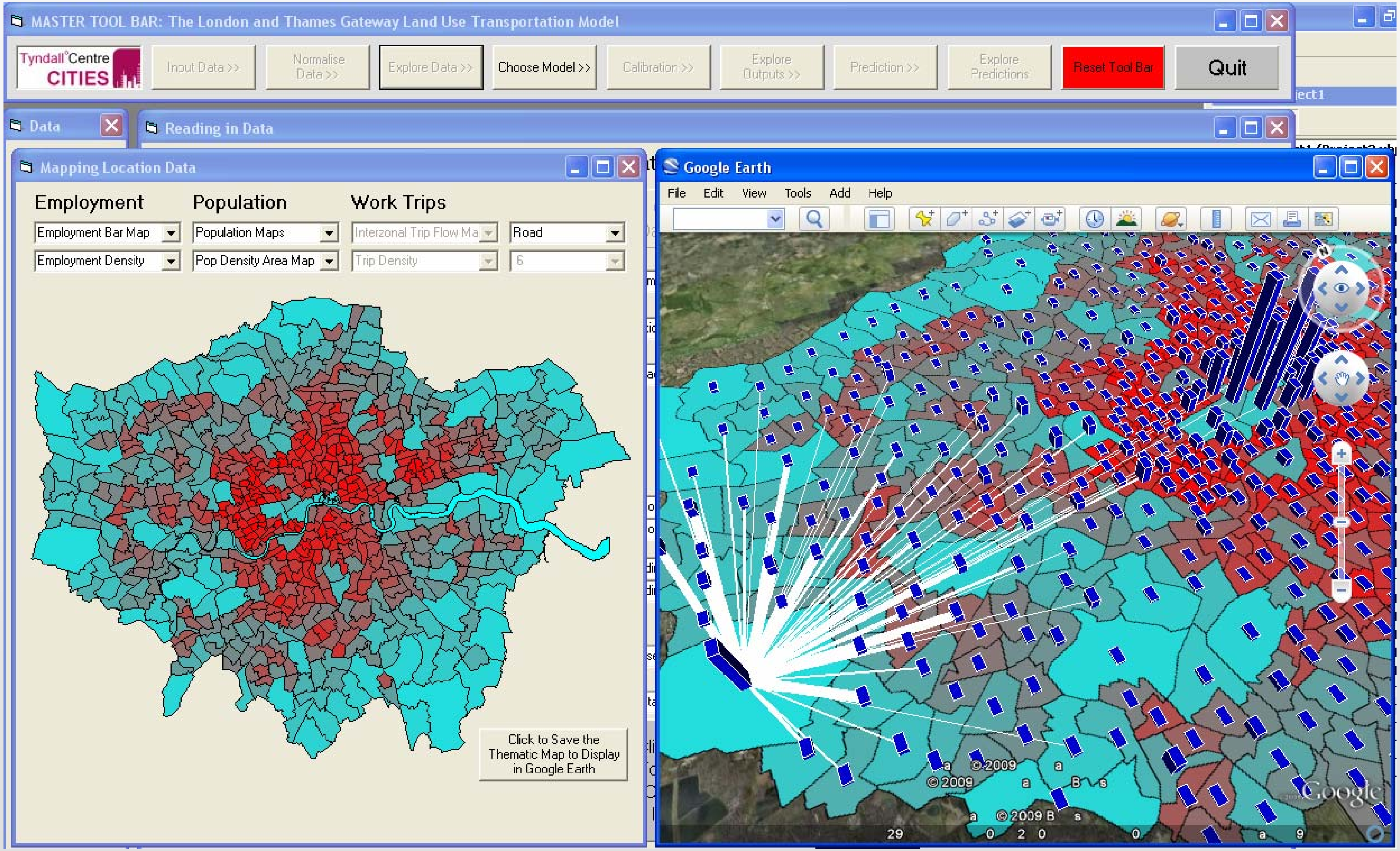
We also needed to communicate these ideas to other modellers, such as the flood modellers, the input-output people and so on

Hence our focus still on visualisation, besides the sort of complexity that these ideas portrayed which we believe requires visualisation at every stage of the process.


MoSeS
UK I-O Model
LUTM
Emissions Modelling
Pop Site Model
Global Climate Models
Flood Models
Local Climate


Mapping Location Data
Employment
Population
Work Trips
Quit
Zones: London Boroughs


Accessibility Indicators
EmpPop
Origin Access
Dest Access
Quit
Zones: 633 Wards in 2001
Locate Zone
Clear Zone Nodes



Exporting data and predictions to external software on the fly

SIMULACRA: ARCADIA and SCALE Projects

SIMULACRA[1] is a generic set of models that we are building for a series of projects, first the ARCADIA project that is an extension of Tyndall, and then for another EPSRC Project called SCALE which deals with energy change in large cities

We are very keen on building a model framework in which we can develop many different variants, easily and quickly. Visualisation is critical, so is scale, so it speed

I think we are now in a position in this field where we can and should develop lots of variants, which test the robustness of any approach while at the same time, enabling models to be tuned to the problem in hand.

---

[1]*SIMulation of Urban Landuse, And Commercial and Residential Activities*

We want to be able to do the following:

Alter and aggregate the zoning system quickly and easily, on the fly almost

Alter by adding and deleting different model sectors, so for example running a model based on simply the retailing and other employment sectors without the residential and so on

Subjecting the model to various kinds of physical constraints, at will and according to external policies

Extending all sectors to not only predict endogenous activities but to also be subject to exogenous inputs of the same

To interface the models easily and quickly with other sectoral models, particularly demographic and possibly more established transport models

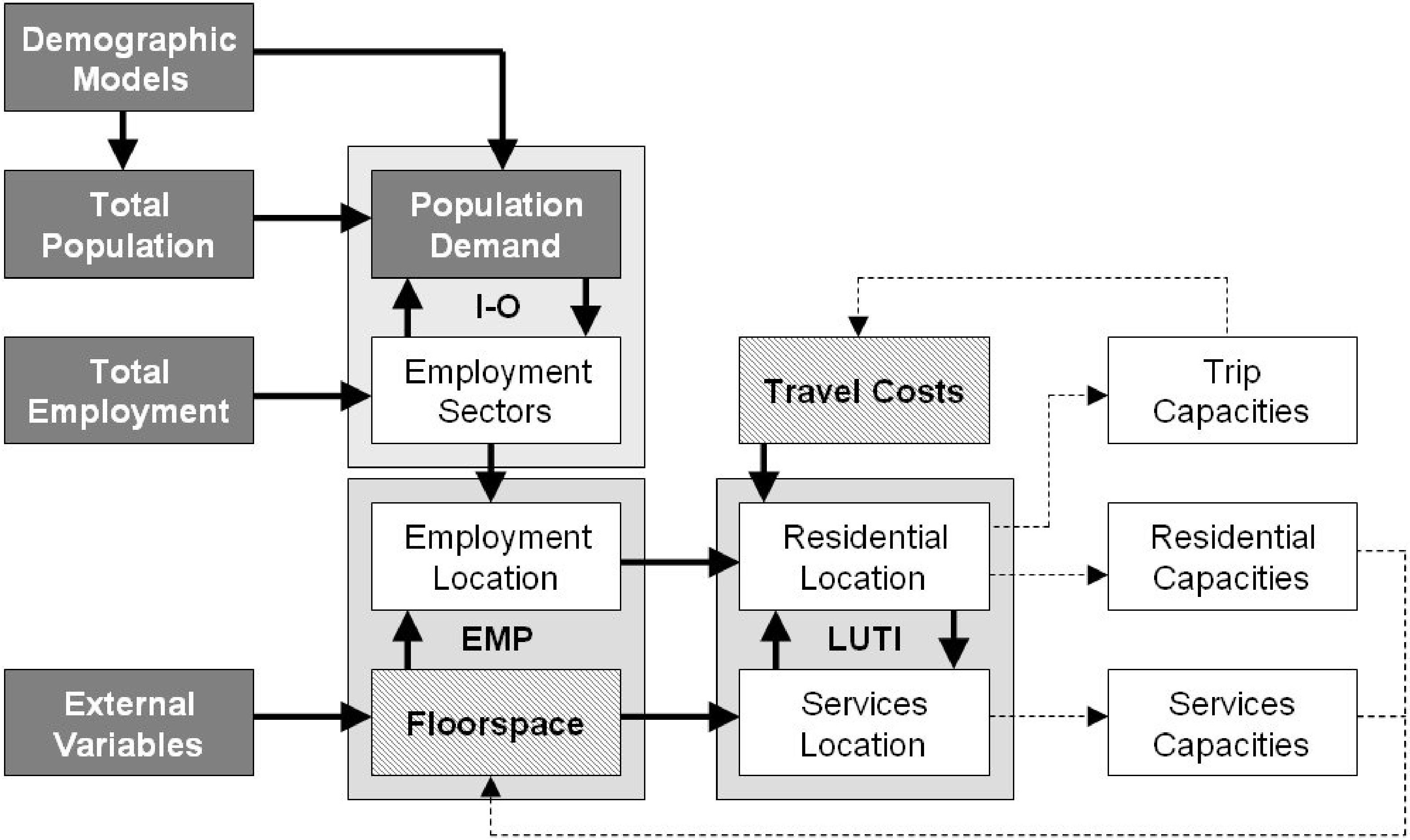
Requirements: The Model Design: Models Flows: Physical Movements, Money, the Employment and Residential Models

We will now show the current model to present the logic of our framework. Our model has now been scaled up massively to include the outer met area – 1767 zones (33 – 633 – 1767 – and then 3202)

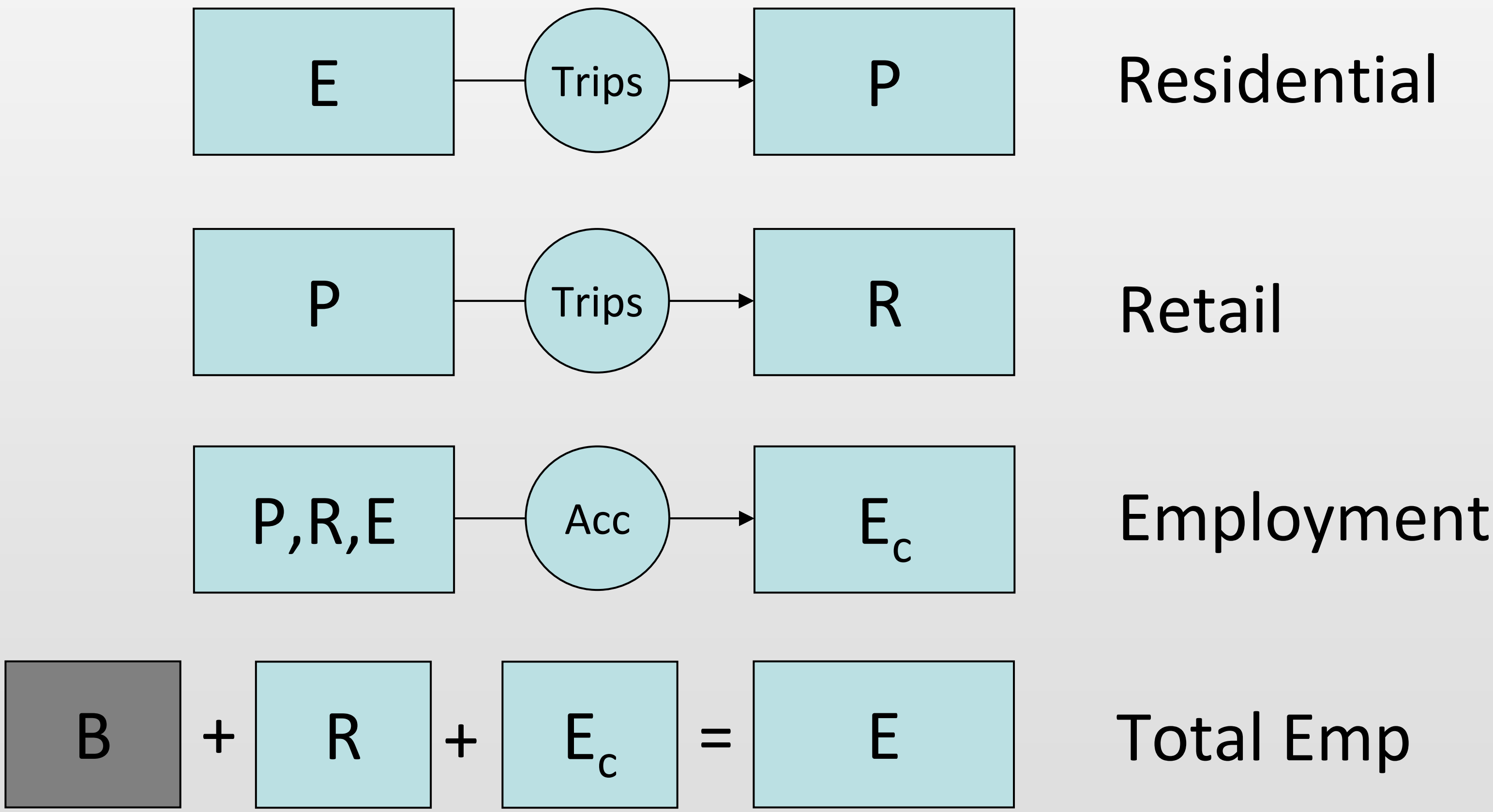
It is now a three sector model, not simply a residential location model as it includes employment location, retail location and residential location

So far, we now have modal split into 2 modes with 4 population categories and 6 employment types in terms of occupations – the model scales up to 48 times the size of the desktop model

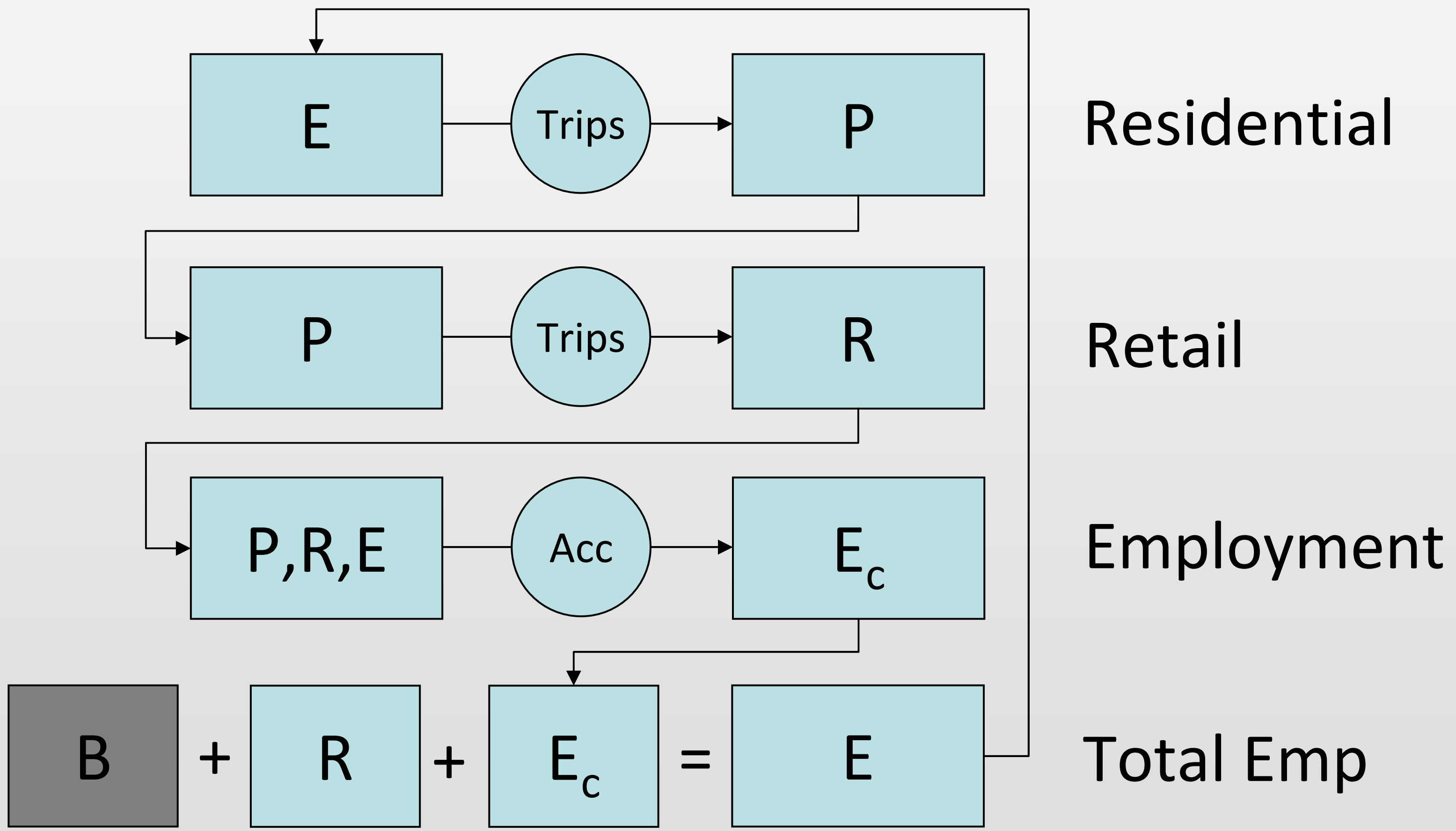
Essentially the model can be pictured as follows:



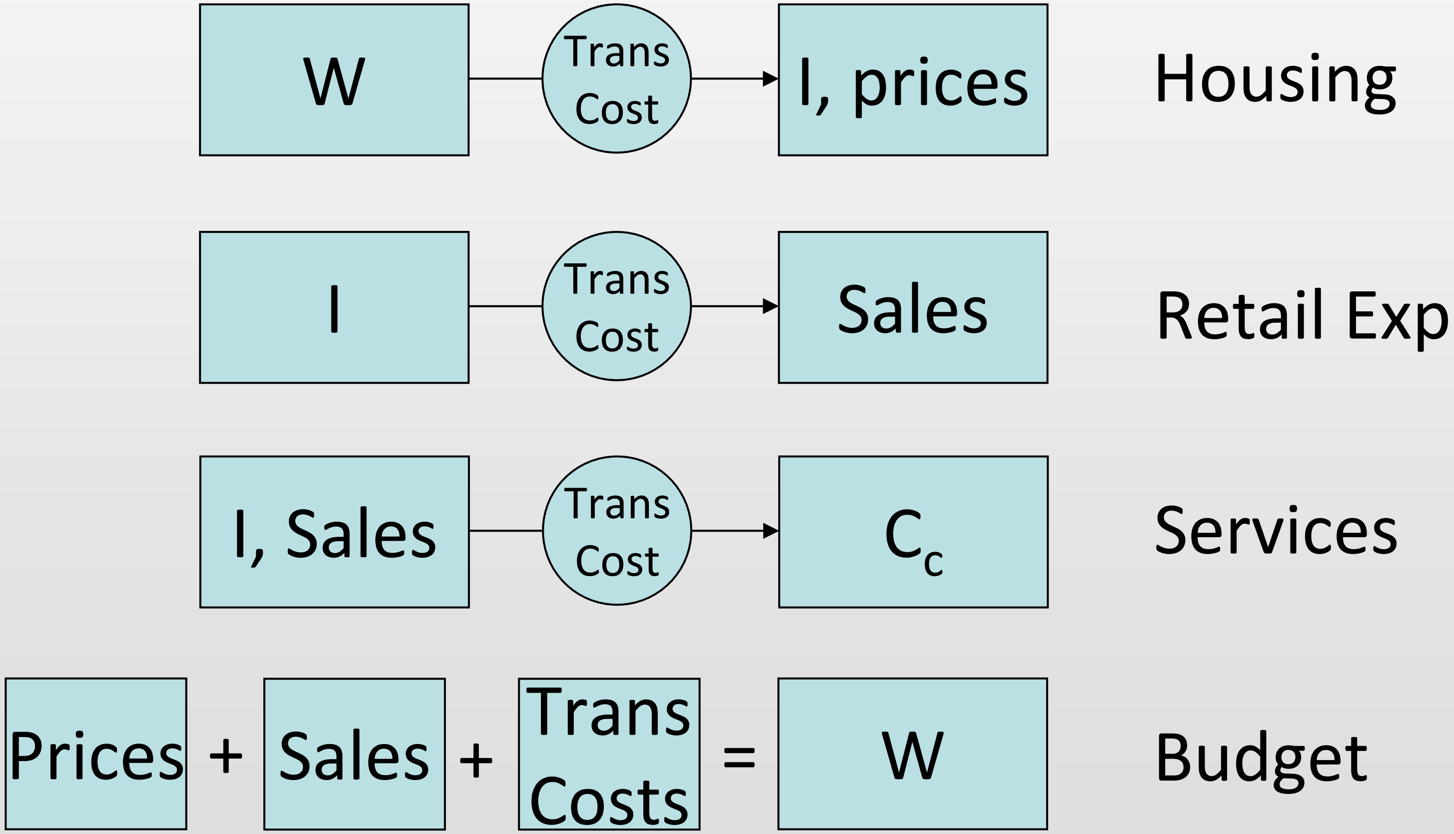
In fact it is easier to show the model structure as follows where we can see how we can elaborate it as a static or dynamic equilibrium model in terms of physical flows



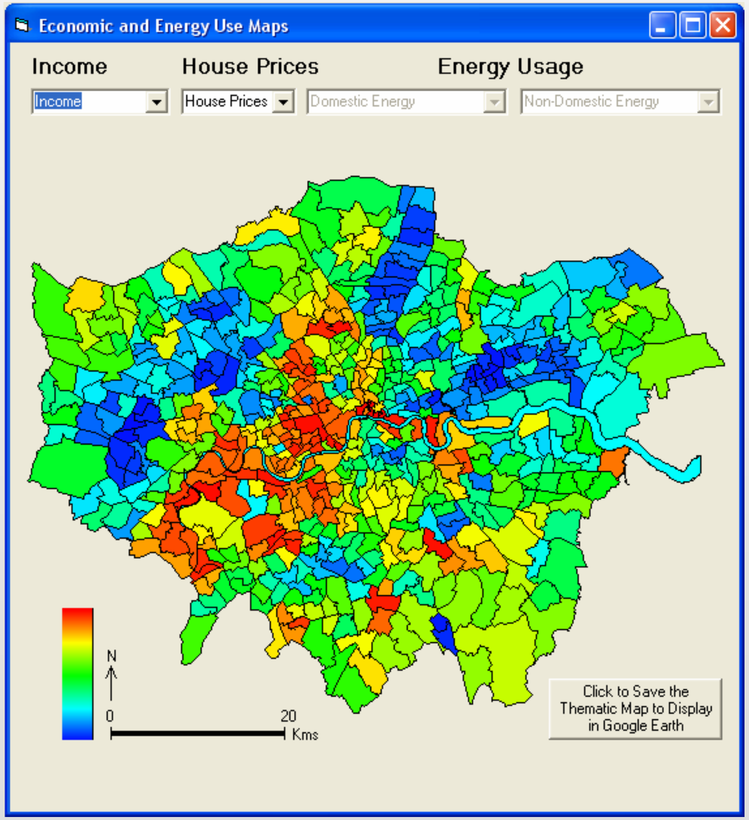
We can now show many ways in which these modules might be connected into an equilibrium framework: this is just one.

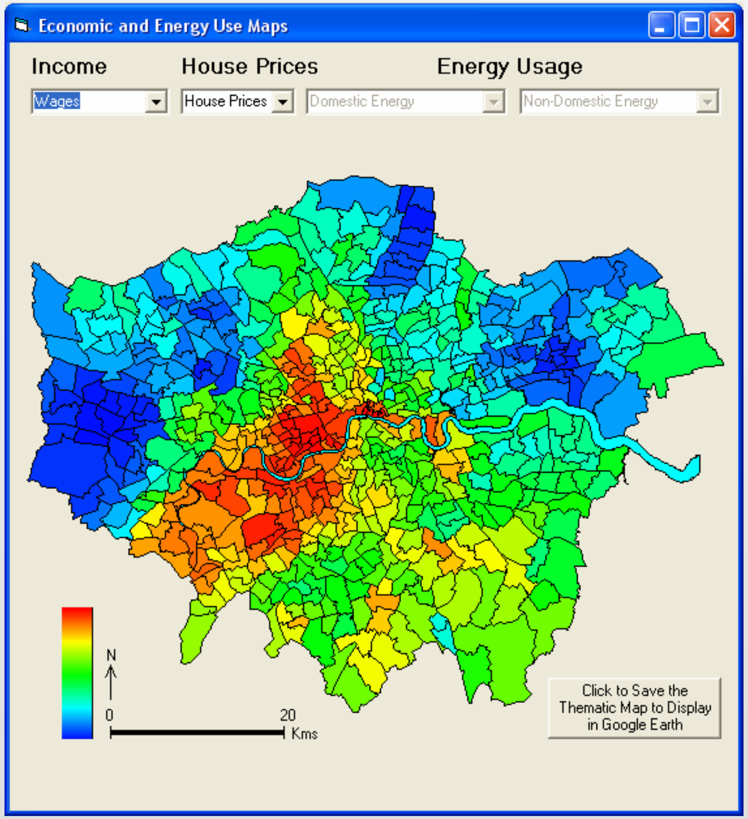


We can have also developed this model in money flows rather than physical flows with wages driving the process



I want to just show very briefly the sort of data that we have in the money sector that is driving this variant of the model and also state the residential location equation so you have some sense of what is going on





And the aggregate residential model is formalised as

with travel as a difference or variance σ^2 between these two sets of costs. Then, the system must satisfy the constraint

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

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).

The employment model has been built recently and it much wider in scale than the current 1767 model – it has 3202 or so zones and this is largely because we need to capture locational change in the wider region.

The model is econometric based on predicting floorspace which in turn predicts employment. The two typical equations

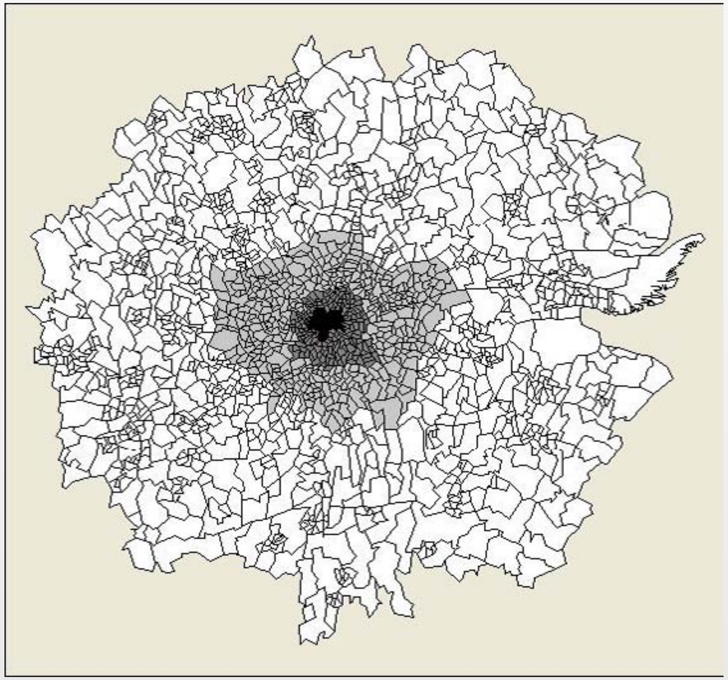
The models that have been fitted are variants of the generic structure that follows:

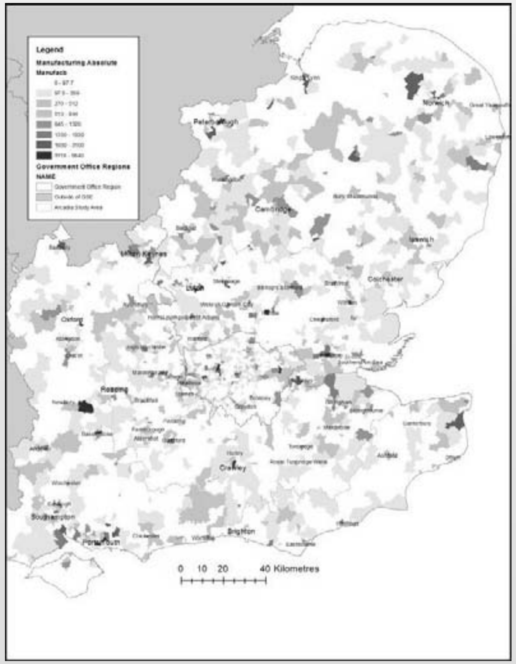
$$F_j^z = a_0 + \sum_{\substack{\ell=1,2,3 \\ \ell \neq z}} a_k F_j^\ell + a_4 B_j + a_5 D_j + a_6 A_j^z + a_7 T_j + a_8 G_j + a_9 H_j + a_{10} Q_j + a_{11} M_j + \sum_{\ell=1,2,3} s_\ell \delta_j^\ell + \sum_{\ell=1,2} f_\ell \delta_j^\ell \qquad (20)$$

similar to that for floorspace and we state it as

$$E_{jk} = b_0 + \sum_{z=1,2,3} b_k F_j^z + b_4 A_j^{PT} + b_5 A_j^R + b_6 M_j + b_7 J_j + b_8 H_j + b_9 h_j + b_{10} Q_j \qquad (21)$$


Scotland
North East
North West
Yorkshire & the Humber
East Midlands
Merseyside
Wales
West Midlands
South West
East
London
South East
Regional Boundary
National Boundary
County Boundary
Regional Government Offices
Berwick
Newcastle
Carlisle
Teeside
Barrow-in-Furness
York
Blackpool
Preston
Leeds
Hull
Liverpool
Manchester
Sheffield
Derby
Leicester
Norwich
Birmingham
Cambridge
Ipswich
Bedford
Gloucester
Oxford
Cardiff
Bristol
Reading
Guildford
Maidstone
Salisbury
Southampton
Brighton
Bournemouth
Exeter
Plymouth
Penzance




0 10 20 40 Kilometres

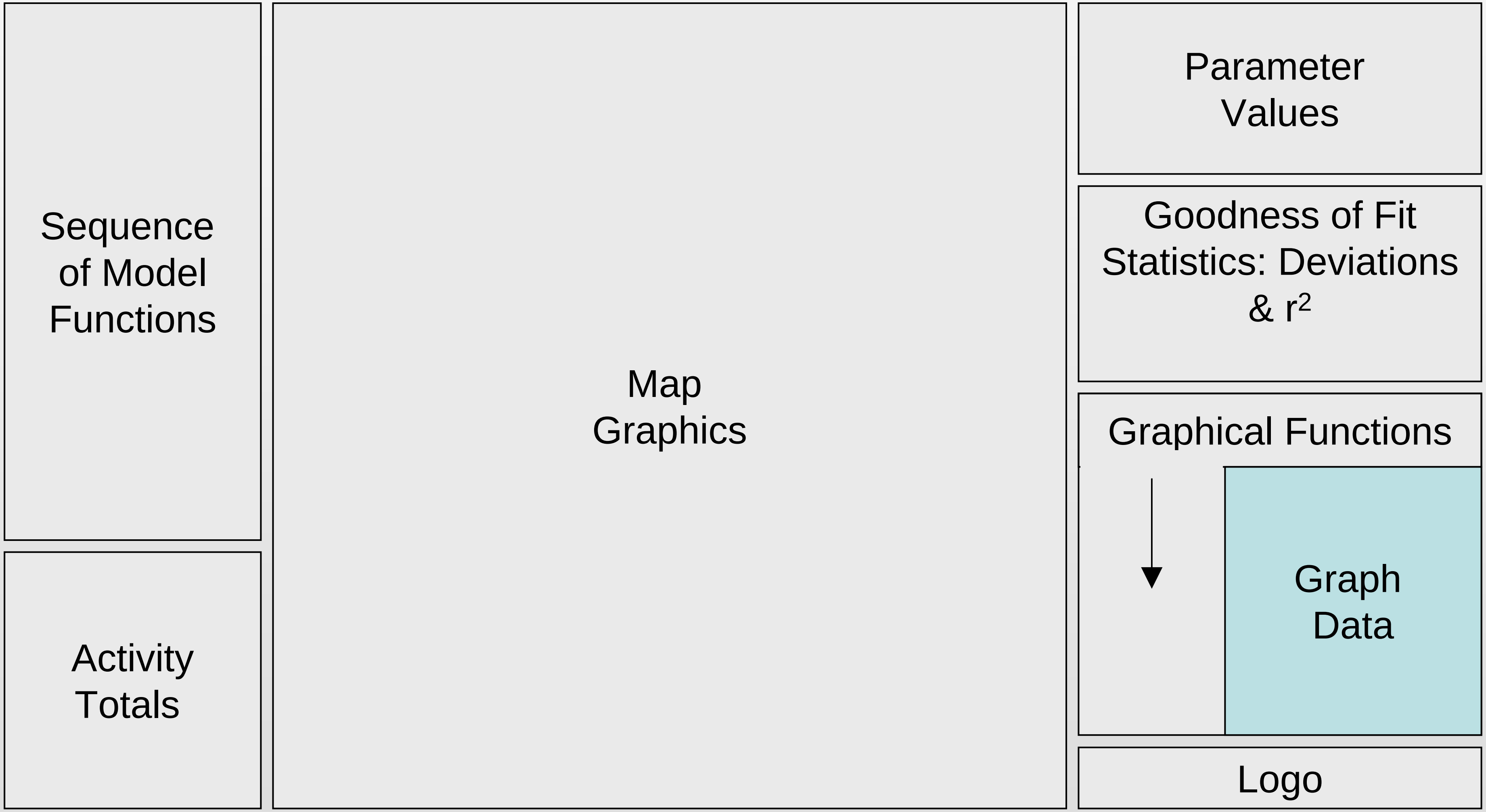
The Visual Template: The Desktop Model

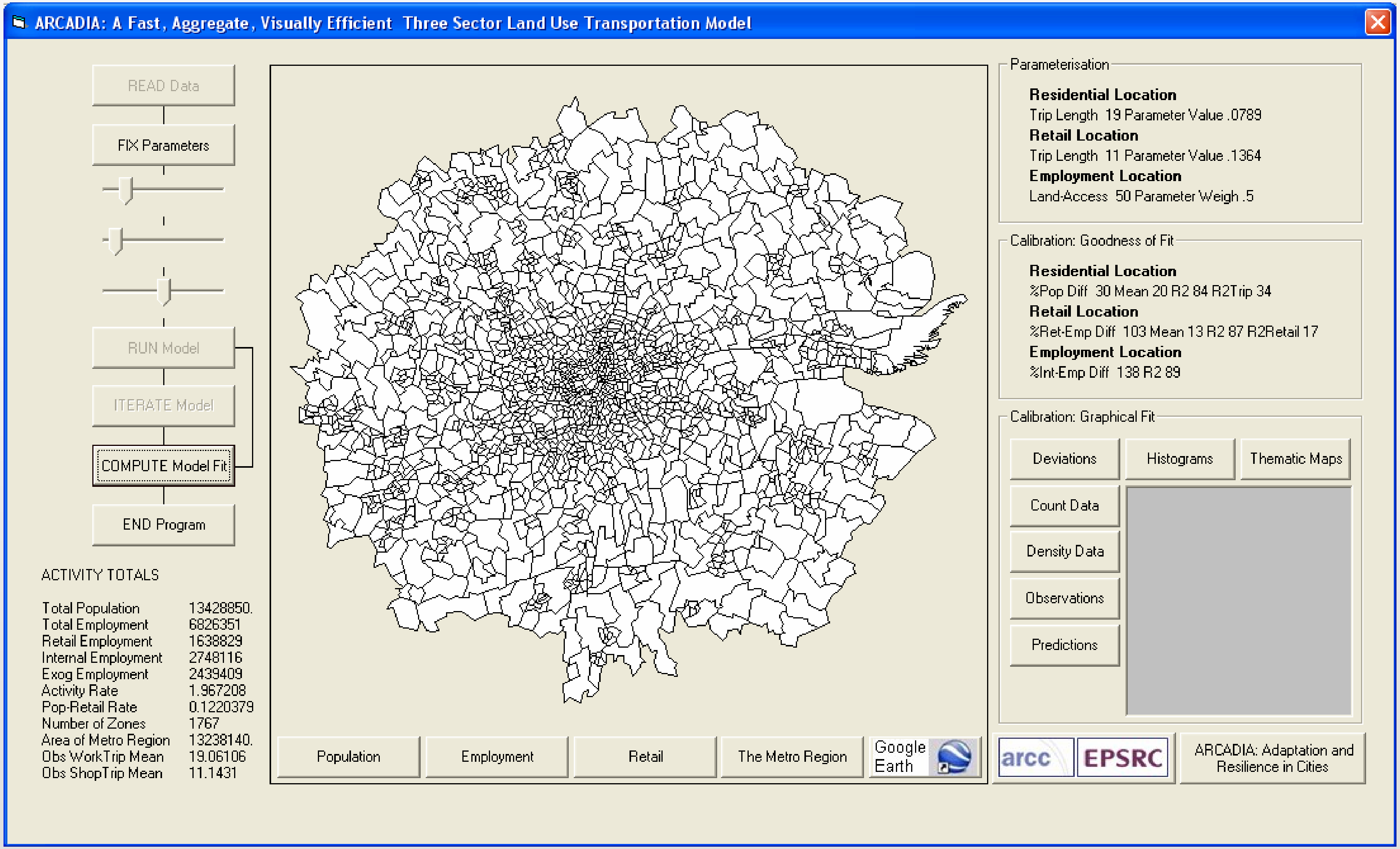
Ok – let me quickly tell you our strategy – we are building a fully fledged model using state of the art software and various web–based interfaces which is highly visual and will be as fast as possible

We are also building a mirror model on the desktop which is my contribution to the project and this is a one window minimal model which is for comparative purposes and to enable the bigger model to be tested

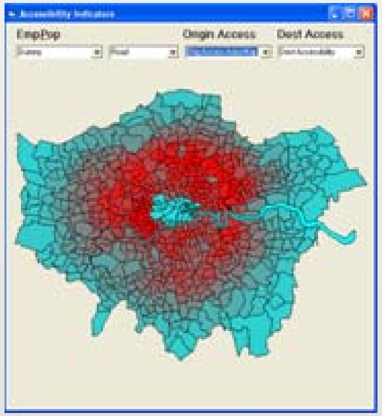
This is the model I will now show and then I will sketch the bigger application very briefly which Camilo in our group is developing

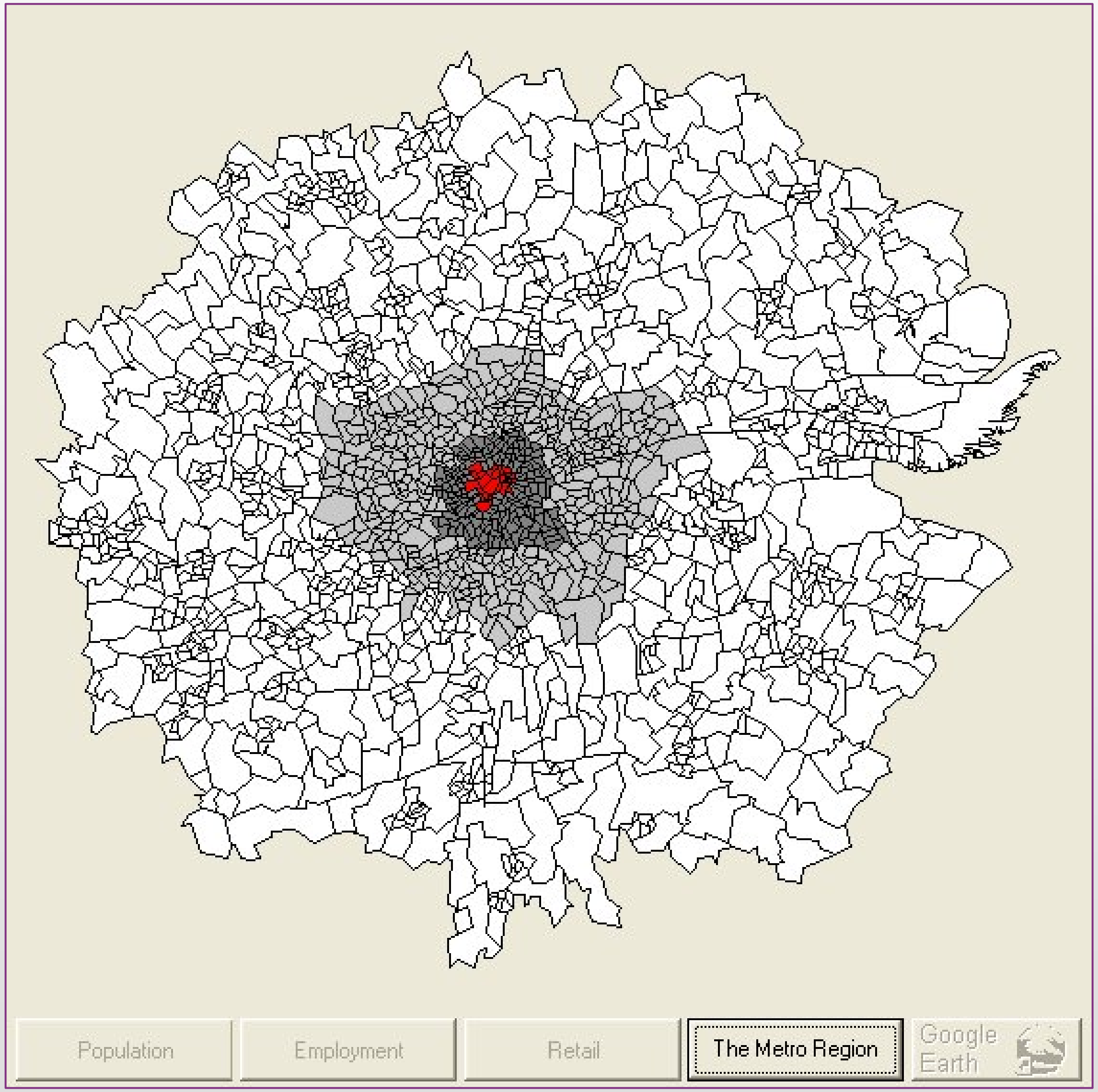
This is the order in which the operations take place



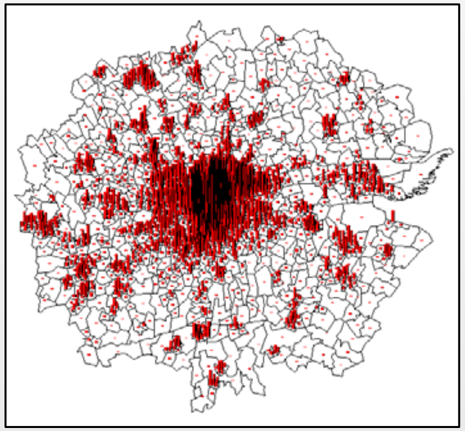
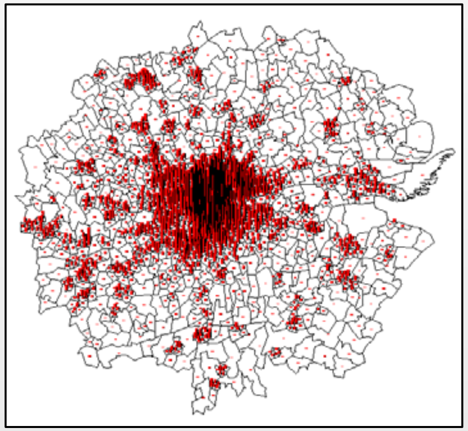
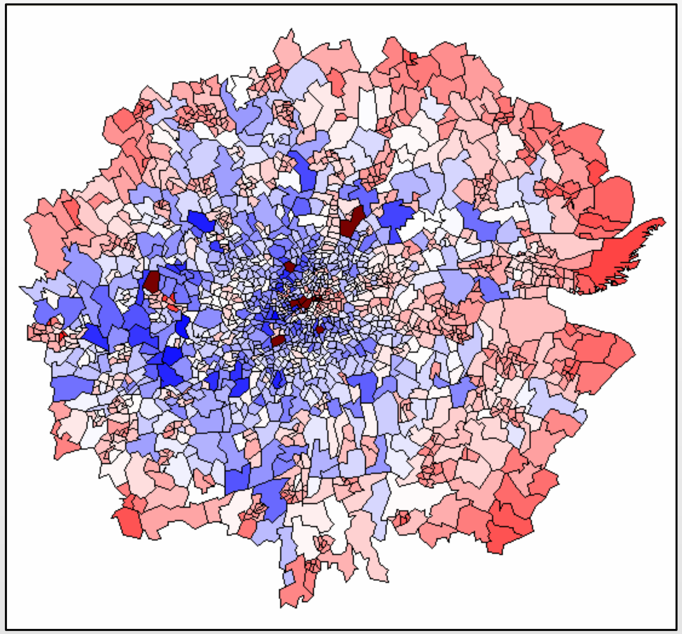
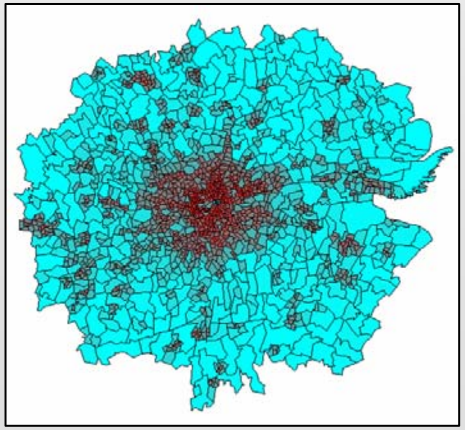
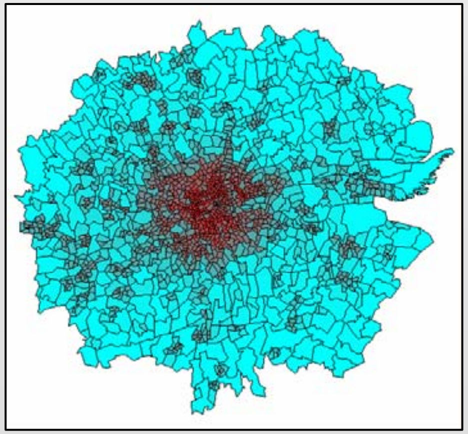

ARCADIA: A Fast, Aggregate, Visually Efficient Three Sector Land Use Transportation Model
READ Data
FIX Parameters
RUN Model
ITERATE Model
COMPUTE Model Fit
END Program
ACTIVITY TOTALS
Total Population 13428850.
Total Employment 6826351
Retail Employment 1638829
Internal Employment 2748116
Exog Employment 2439409
Activity Rate 1.967208
Pop-Retail Rate 0.1220379
Number of Zones 1767
Area of Metro Region 13238140.
Obs WorkTrip Mean 19.06106
Obs ShopTrip Mean 11.1431
Population
Employment
Retail
The Metro Region
Google Earth
Parameterisation
Residential Location
Trip Length 19 Parameter Value .0789
Retail Location
Trip Length 11 Parameter Value .1364
Employment Location
Land-Access 50 Parameter Weigh .5
Calibration: Goodness of Fit
Residential Location
%Pop Diff 30 Mean 20 R2 84 R2Trip 34
Retail Location
%Ret-Emp Diff 103 Mean 13 R2 87 R2Retail 17
Employment Location
%Int-Emp Diff 138 R2 89
Calibration: Graphical Fit
Deviations
Histograms
Thematic Maps
Count Data
Density Data
Observations
Predictions
arcc
EPSRC
ARCADIA: Adaptation and Resilience in Cities


Employment
Population
Work Trips


EmpPop
Origin Access
Dest Access

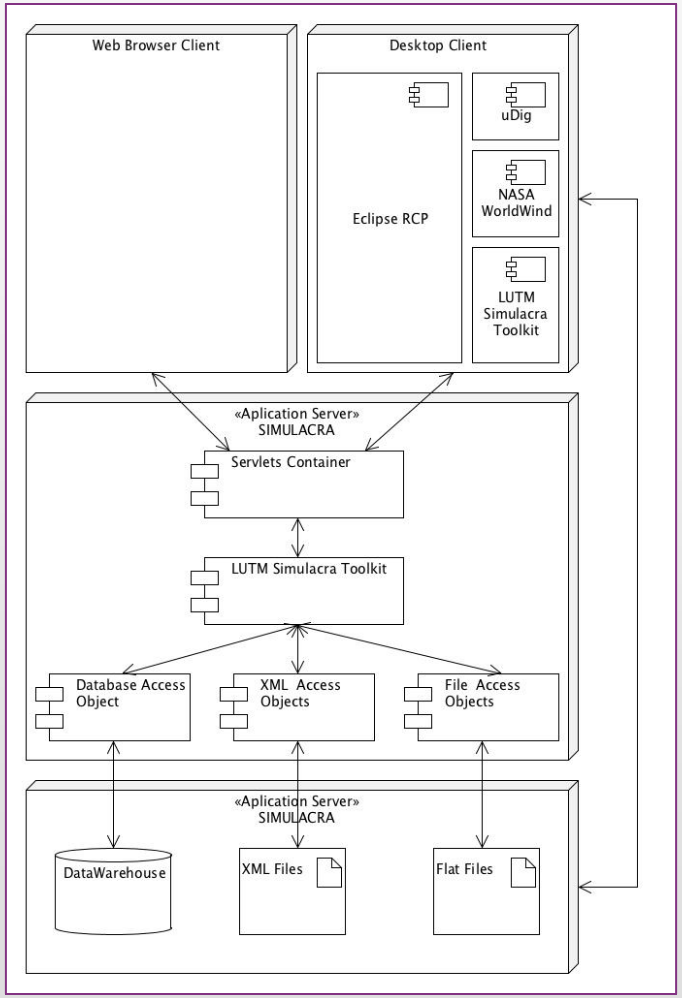

Population
Employment
Retail
The Metro Region
Google Earth

Here are some sample outputs – I will run the model as speed is important – here goes

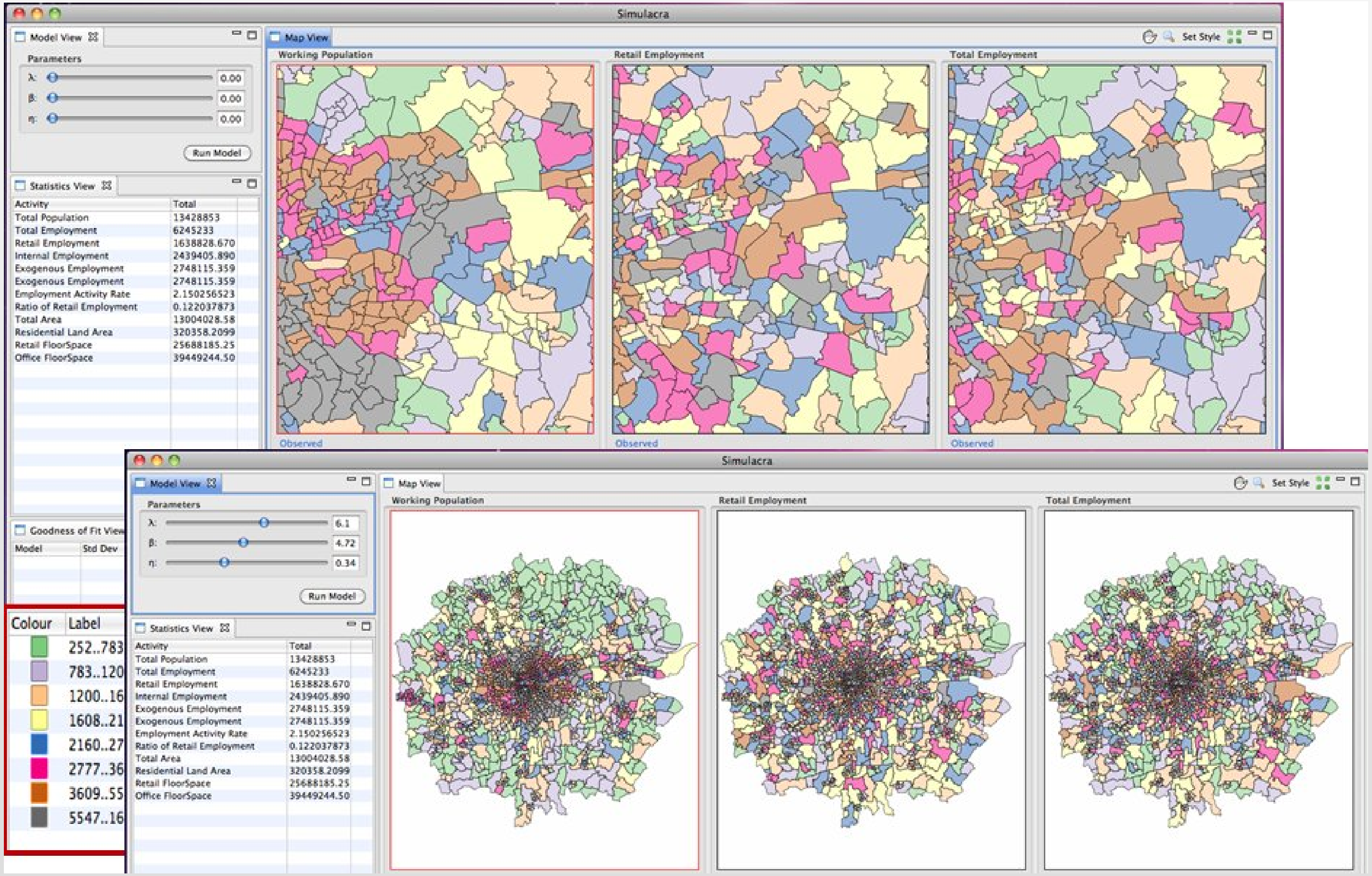






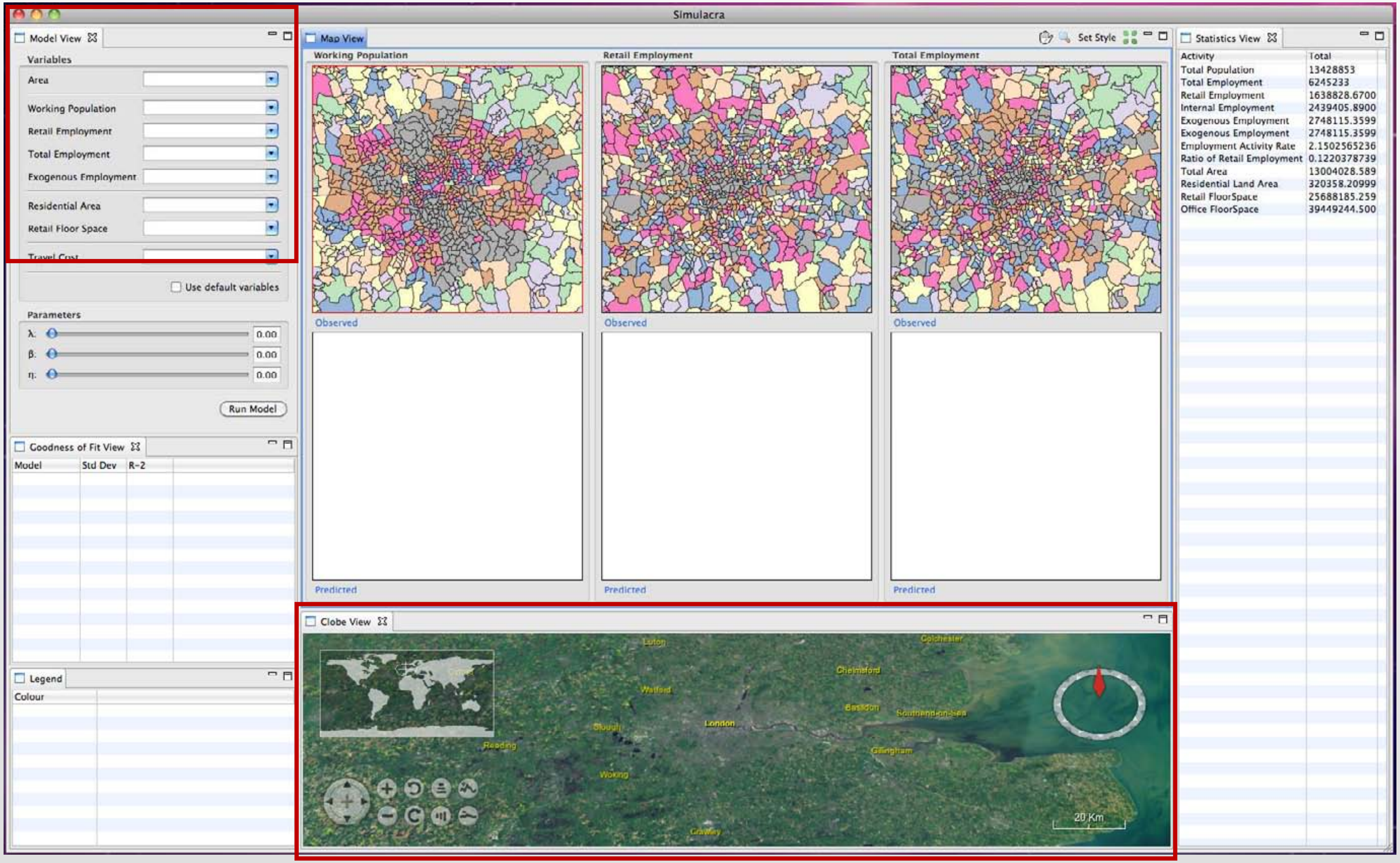
Ok I will run the model from here – in fact I need to go to the file

Building a Web-Based Model Interface



And here are some screen shots from the desktop version of this ultimately to be a web based application – on Mac and PC




Simulacra
Model View
Variables
Area
Working Population
Retail Employment
Total Employment
Exogenous Employment
Residential Area
Retail Floor Space
Travel Cost
Use default variables
Parameters
λ. 0.00
β. 0.00
η. 0.00
Run Model
Goodness of Fit View
Model
Std Dev
R-2
Legend
Colour
Map View
Set Style
Working Population
Retail Employment
Total Employment
Observed
Predicted
Globe View
London
20 Km
Statistics View
Activity Total
Total Population 13428853
Total Employment 6245233
Retail Employment 1638828.6700
Internal Employment 2439405.8900
Exogenous Employment 2748115.3599
Exogenous Employment 2748115.3599
Employment Activity Rate 2.1502565236
Ratio of Retail Employment 0.1220378739
Total Area 13004028.589
Residential Land Area 320358.20999
Retail FloorSpace 25688185.259
Office FloorSpace 39449244.500

Data Bases: Location, Interactions & Networks

We have a big problem in getting the networks sorted out for the aggregate model as these networks are at a very fine scale

We need them to be at a coarser scale for the model as we need to do all the assignment and capacity checking at the level of the model

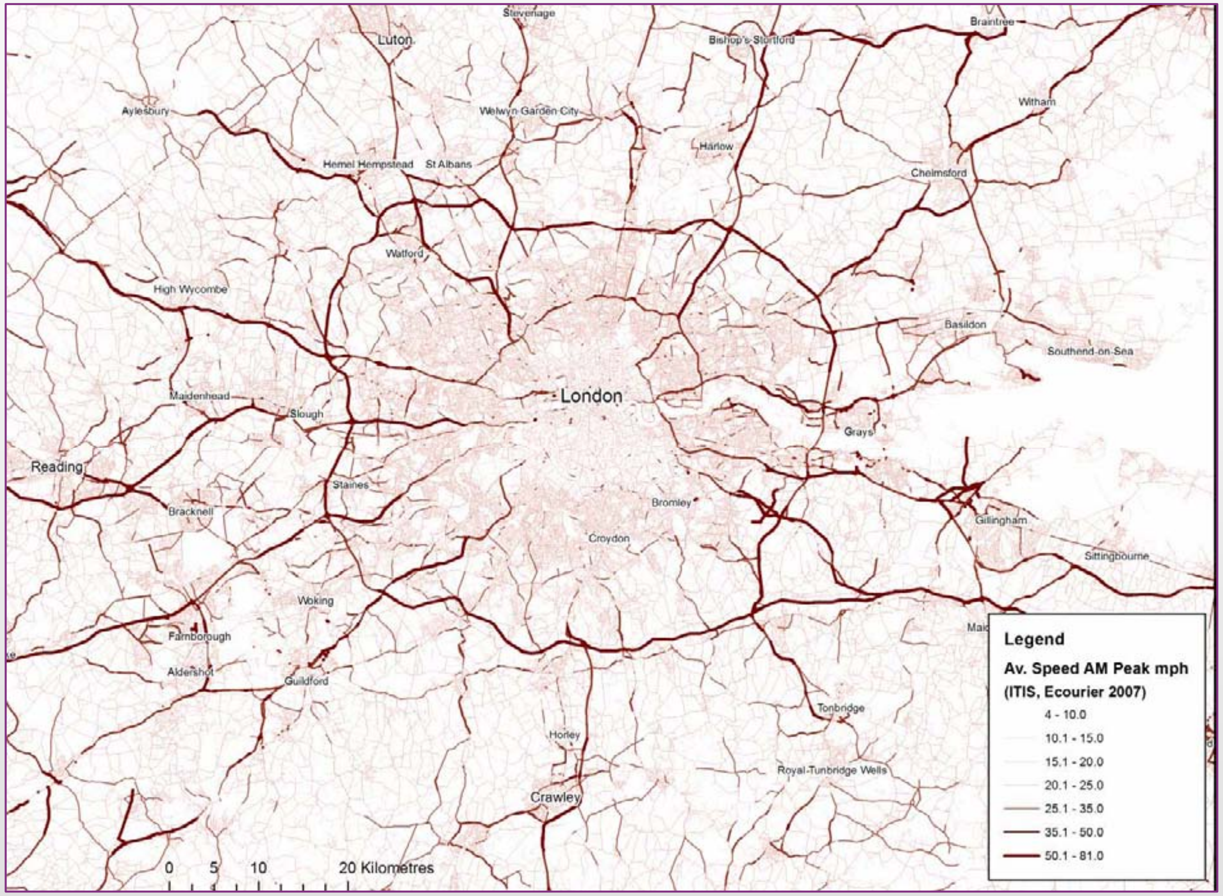
This is a long standing issue, we know, but we cannot afford to move down the local fine scale level to do the assignment of trips to the network because this would simply destroy our basic principle of accessibility of the model to users and also the speed requirements we need

We will show some of the detail we have by way of illustrating our work in progress.

Road Costs

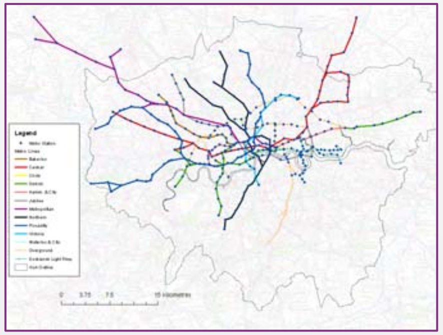
Used GPS data for realistic road speeds across the South East. Sourced from ITIS and Ecourier.

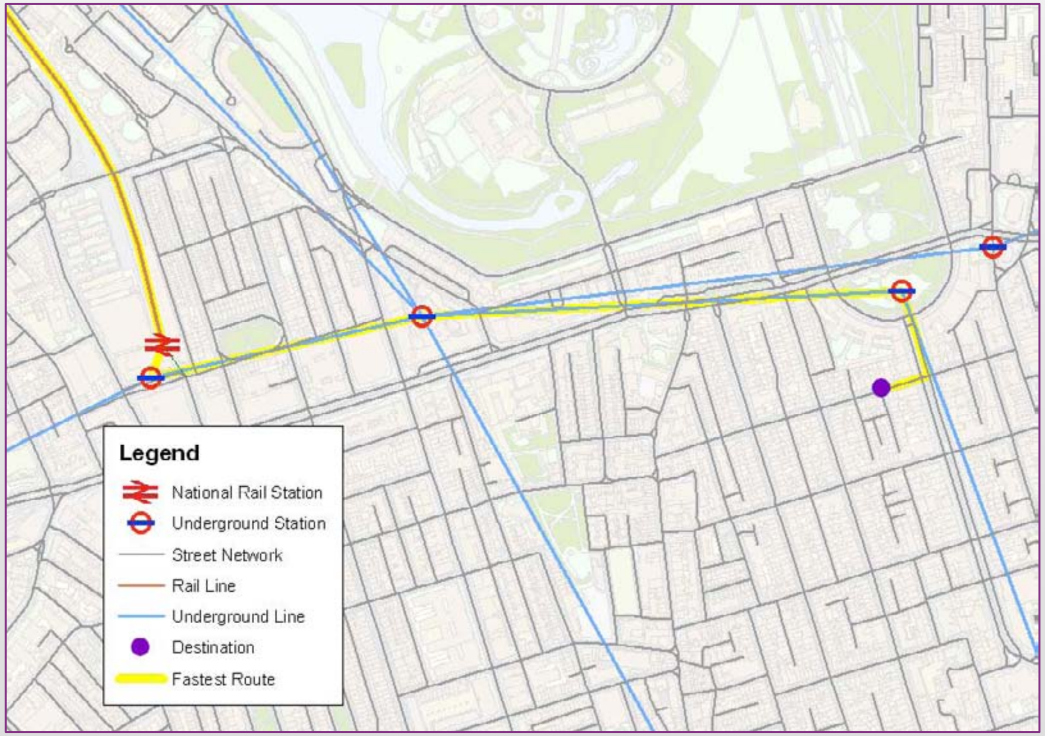
Future improvements with dynamic consideration of congestion.



Public Transport Costs

Based on network geometry and timetabled services. Initially using model presented by Duncan last term. Allows multi-modal PT trips.





TransXchange

Full UK PT timetable available in XML format. Could be used to automate process of generating PT networks.

Key Challenges for Immediate Developments

- Speed of Models
- Quick and Effective Visualisation
- Running the Model with Users/Stakeholders
- Building a Residential Model Based on the Housing Market Cost, prices, travel and energy costs etc - The Wegener Principle
- Moving to a Semi-Dynamic Model with Inertia and Internal Migration
- A Local UK Dimension: Thinking of the Modelling Strategy as being Informed by National Data Bases such as Neighbourhood Statistics

I would like to refer you to our Blog on this

http://simulacra.blogs.casa.ucl.ac.uk/

http://www.complexcity.info/

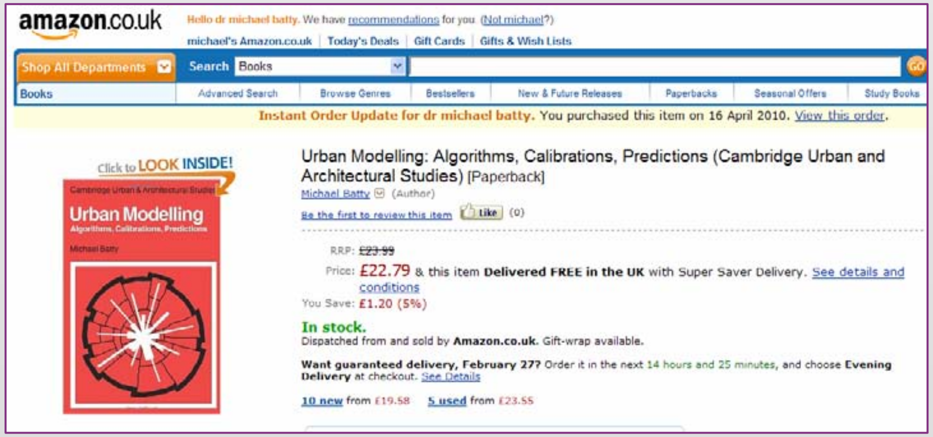
www.casa.ucl.ac.uk

And some papers

M. Batty (2012) Urban Regeneration as Self-Organisation, **Architectural Design, 215**, 54-59

D. Smith, C. Vargas-Ruiz, & M. Batty (2012) Simulating the Spatial Distribution of Employment in Large Cities: with Applications to Greater London, **CASA Working Paper No 177**

M. Batty, D. Smith, J. Reades, A. Johansson, J. Serras, C. Vargas-Ruiz (2011) Visually-Intelligible Land Use Transportation Models for the Rapid Assessment of Urban Futures, **CASA Working Paper No 163**



You can download the **Urban Modelling** book from my other blog www.complexcity.info