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7th Annual Getis-Ord Lecture in Spatial Analysis

Scaling Up Urban Models:
Web-Based Simulation & Visualisation

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Outline

- Land Use Transportation Interaction (LUTI) Models: A Little Bit of History and Some Context
- Our London Models: Tyndall, ARCADIA, Simulacra
- The Visual Template: The Desktop Model: Running It for The Larger London Region and for Dubai
- New Models: Money Flows, Hierarchical-Multilevel, Data Driven, …
- Building a Web-Based Model Interface
- The QUANT Model: For Very Large Areas, Nations,
- Speeding It Up and Extending it to Scotland
- Building Scenarios: Testing Large Scale Urban Impacts, in Particular New Railways

Land Use Transportation Interaction (LUTI) Models: A Little Bit of History

Early models: CATS 1955: The 1960s Models

Computational Limits: Detail of the Spatial System

Problematic System-Environment Interactions

No Visualisation: Hard to Evaluate Model Outcomes

Awful Data, Remote from Policy Analysts

Models in Equilibrium: Very Rudimentary Theory: Urban Economics and Social Physics

The Reaction: The Requiem

Recovery and Slow But Sure Progress – Better Data, Faster Computers but still Poor Theory, Very Poor and the Subject Matter – Cities – is getting more complex

Our London Models: Tyndall, SIMULACRA: ARCADIA Projects

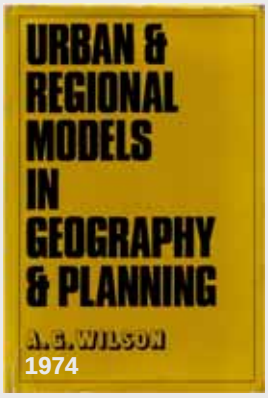
We have been building Land Use Transport Models in CASA for about 10 years.

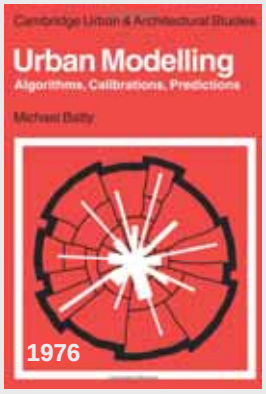
But their origins go back to the 60s. Two of us, myself & Alan Wilson, were there at the beginning, almost.

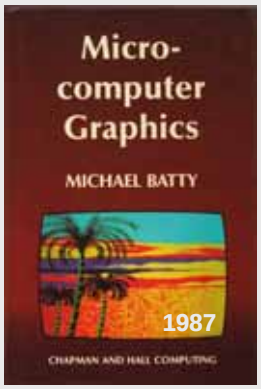
I didn't do much on these in the 1980s for the simple reason that I thought they needed much more graphics with respect to how we interpret their simulations, so I retooled myself in computer graphics.

That took while because I got diverted into fractals which were pretty visual and this took us off into scaling and city science and cellular automata –

The Science of Cities based on scaling, allometry and geometry and physics is another country and I wont say any more about that. Yet LUTI (land use transport interaction models are to a limited extent part of this wider domain.







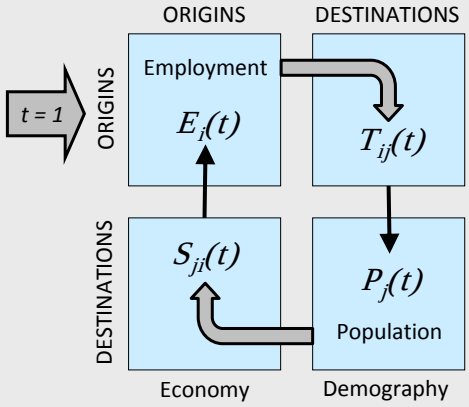
Our first model was for Greater London and I will show it you in about 5 minutes but the key issue was where do we draw the boundary. This was part of a climate change project looking at seal level rise and development

We extended the model in terms of area taking in GLA and what we call the outer met area

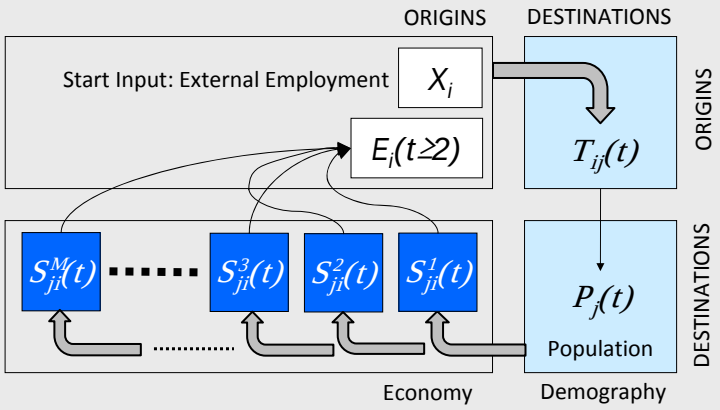
Generically we called these models SIMULACRA loosely alluding to Jean Baudrillard's use of the term – *a simulation of a simulation*

All these models avail themselves of good visualisation, much more immediacy – they run before your eyes – they are fast and visual – that has been our focus – and now we are extending them from the desktop to the web: that is what we call **QUANT**

Let Me Give You A Quick Tutorial On Their Structure:

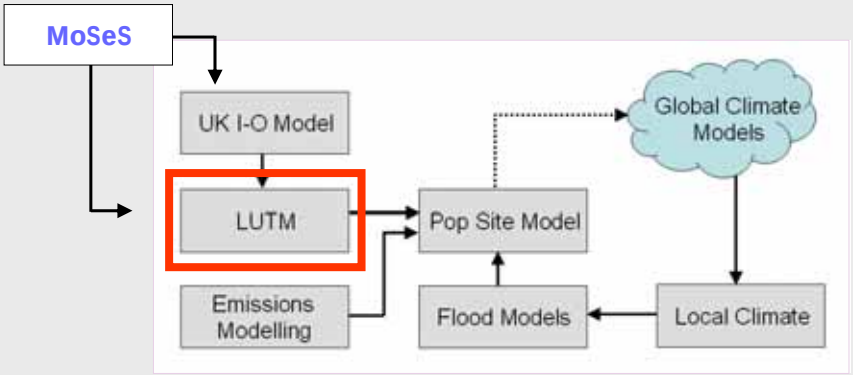


We can expand this structure into multiple sectors. Several LUTi models have done this – e.g. the Cambridge (UK) input-output LUTi such as LUISA



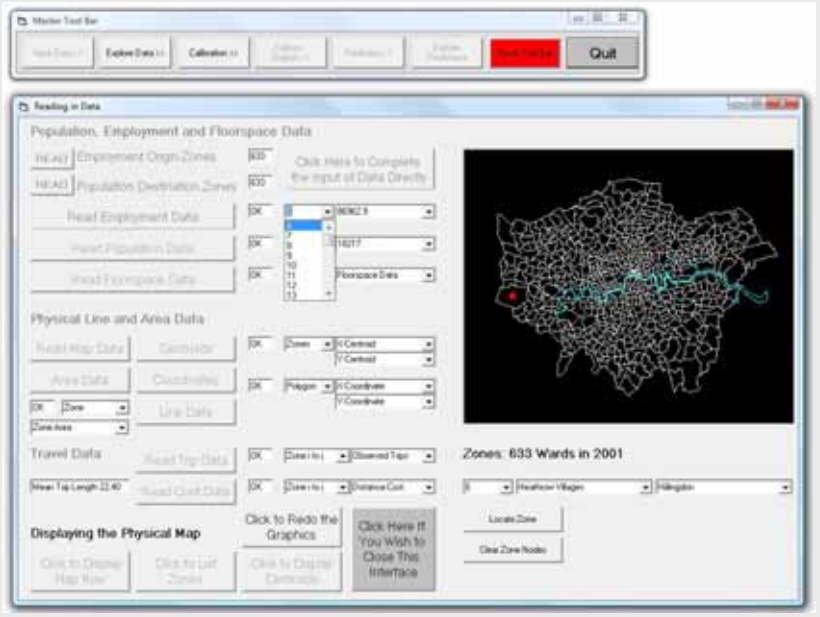
Integrated Assessment

So let me pull these together in my first example

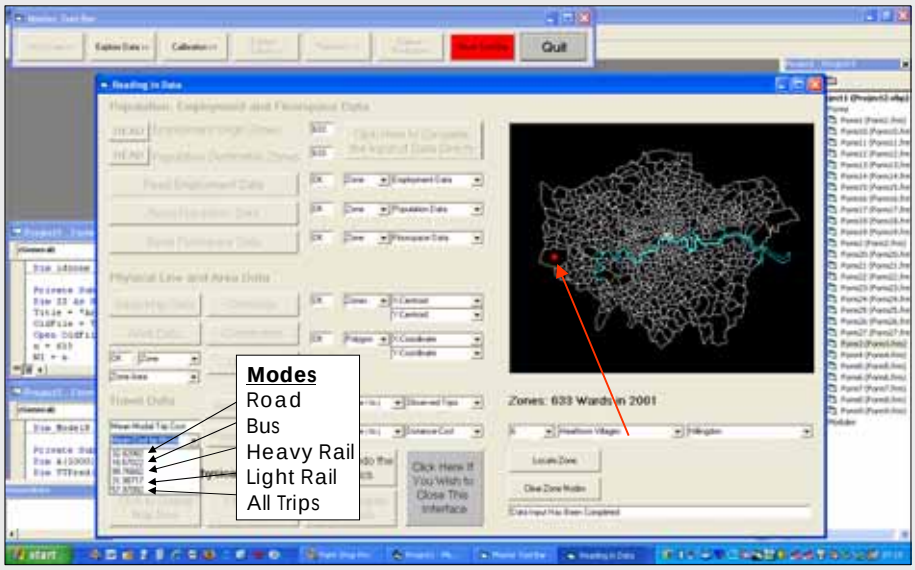


To give a flavour of the LUTI/LUTM model, I will show some screen shots first



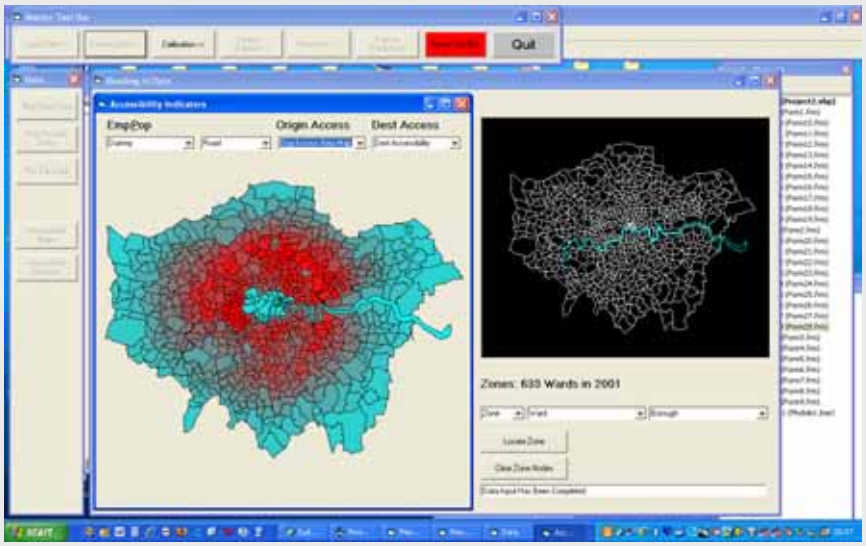


Scaling Up Urban Models

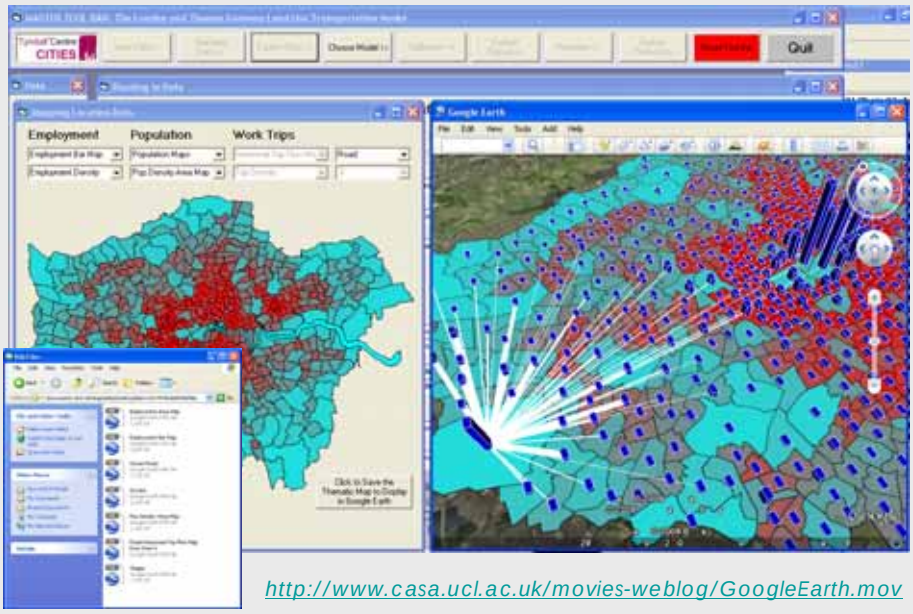


Road: 38%; Bus: 12%: Heavy Rail: 12%: Light Rail 19%; Other (Walk, Bike): 19%

Scaling Up Urban Models

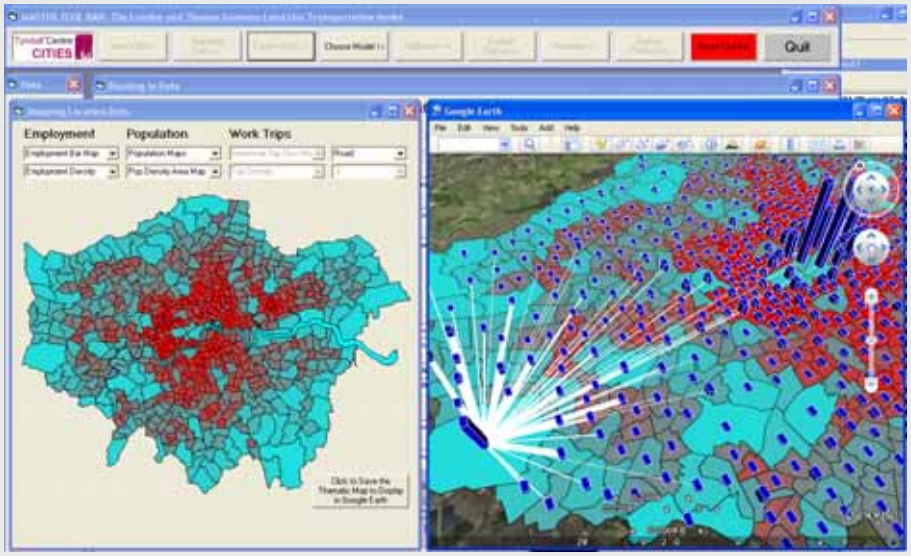


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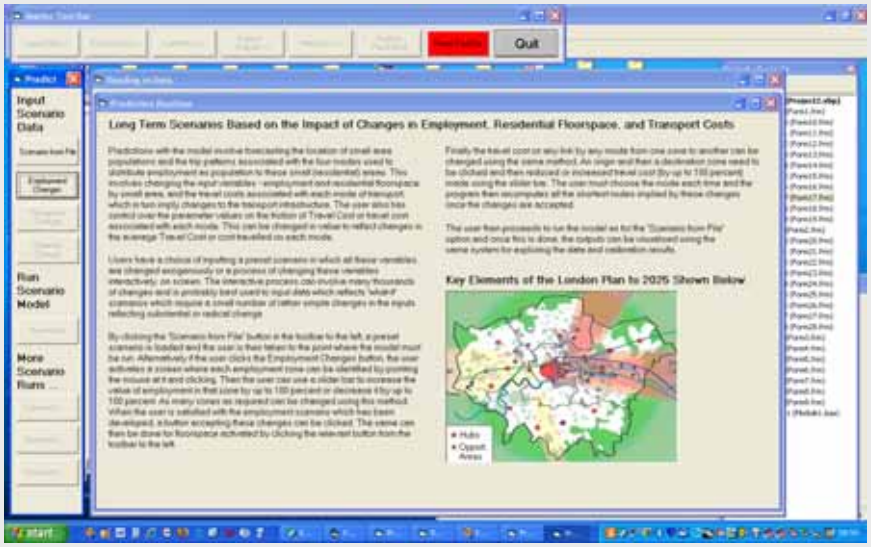


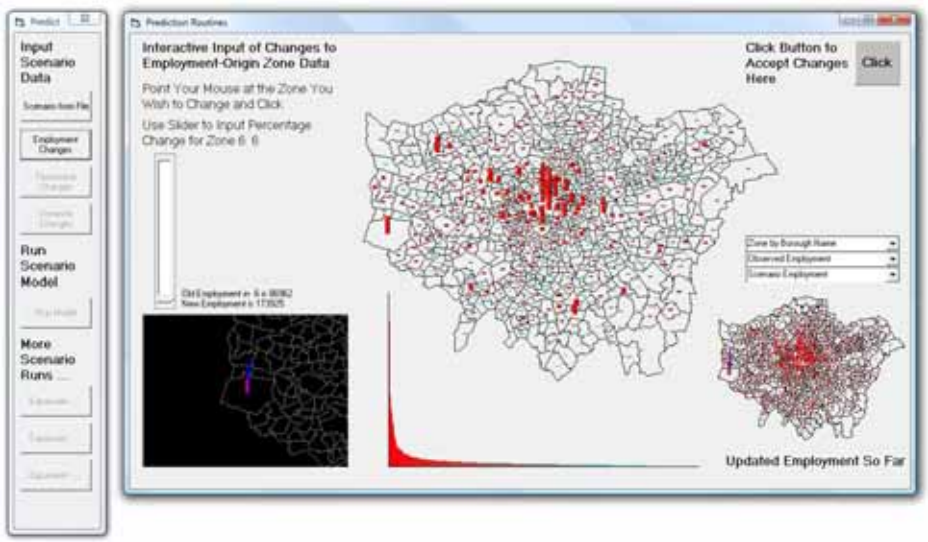
http://www.casa.ucl.ac.uk/movies-weblog/GoogleEarth.mov

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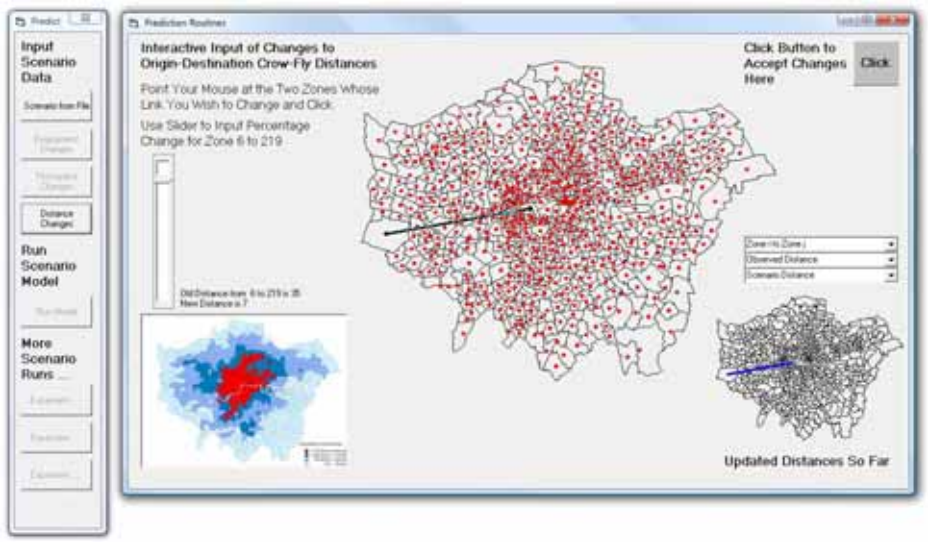


Exporting data and predictions to external software on the fly – here is a demo of this

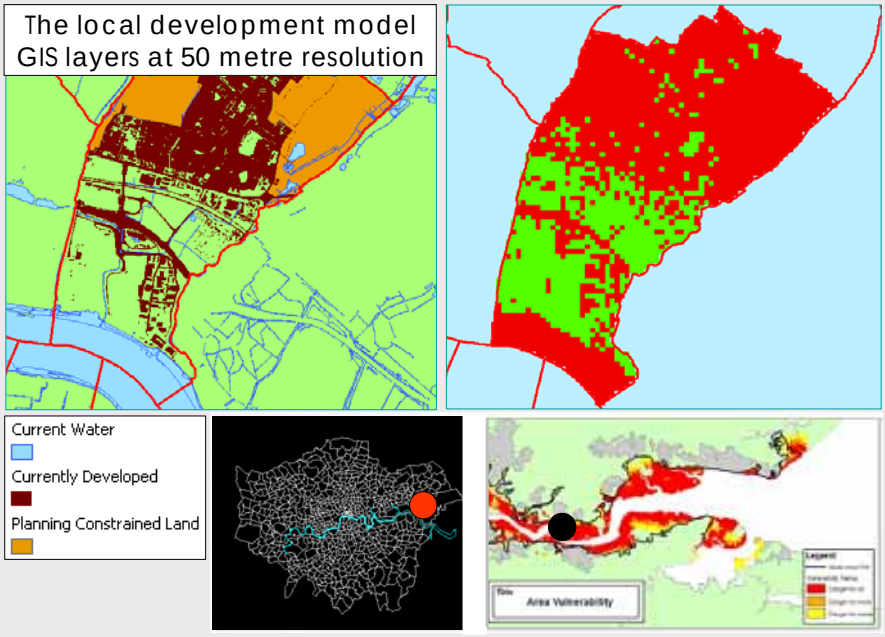




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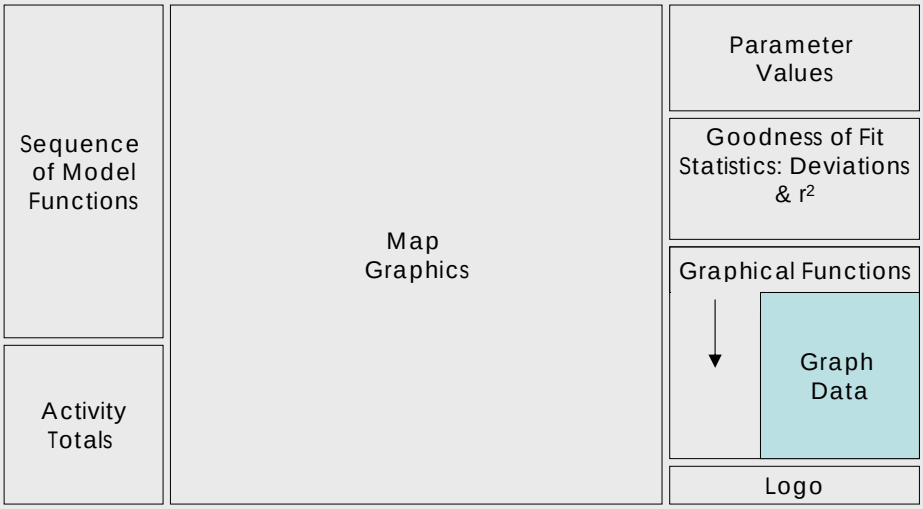
The Visual Template: The Desktop Model: Running It

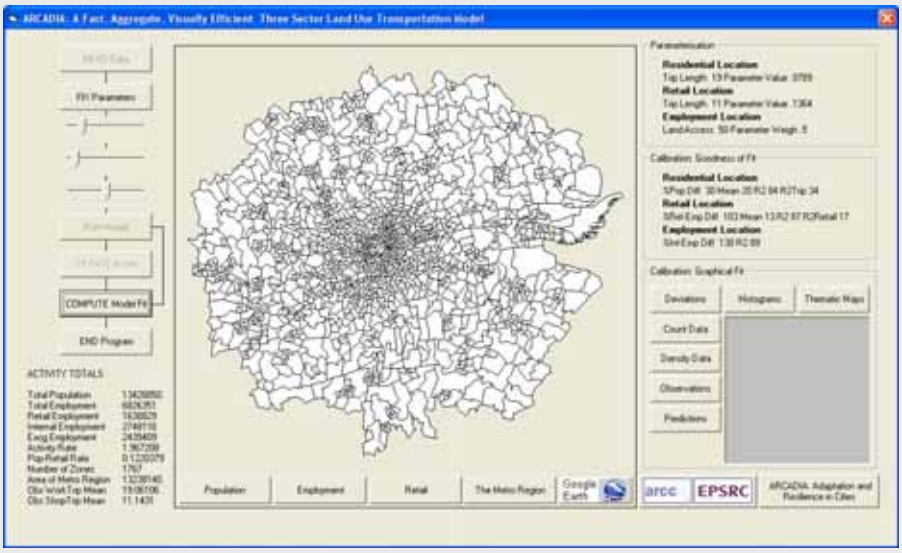
We will now show the current model to present the logic of our framework. Our model has now been scaled up massively to include the outer met area – 1767 zones (33 – 633 – 1767 –and then 3202)

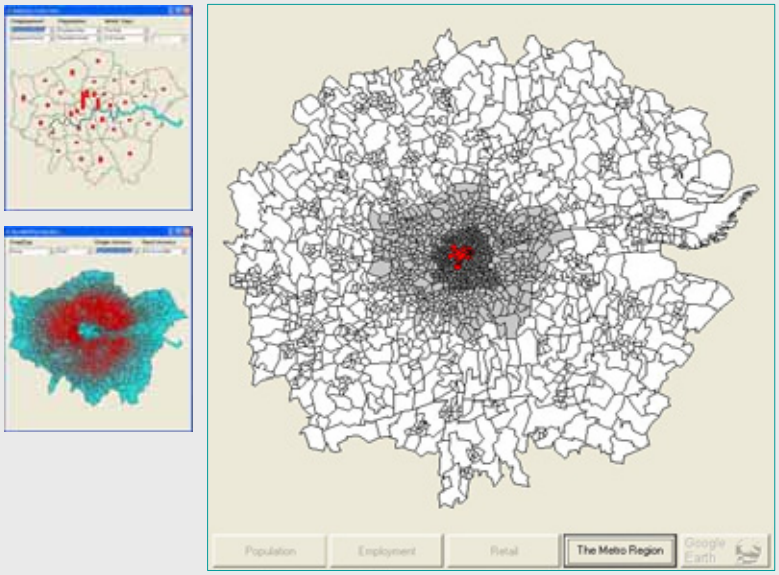
It is now a three sector model, not simply a residential location model as it includes employment location, retail location and residential location

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

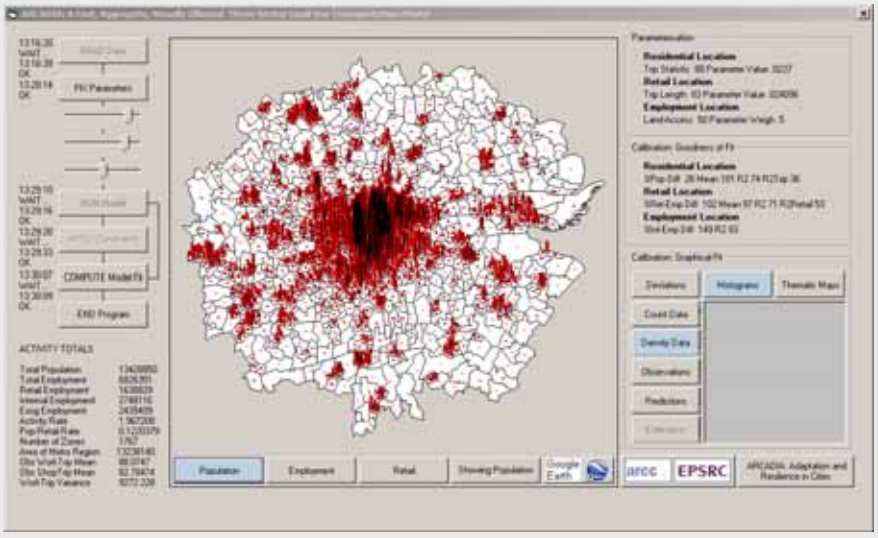
This is the order in which the operations take place



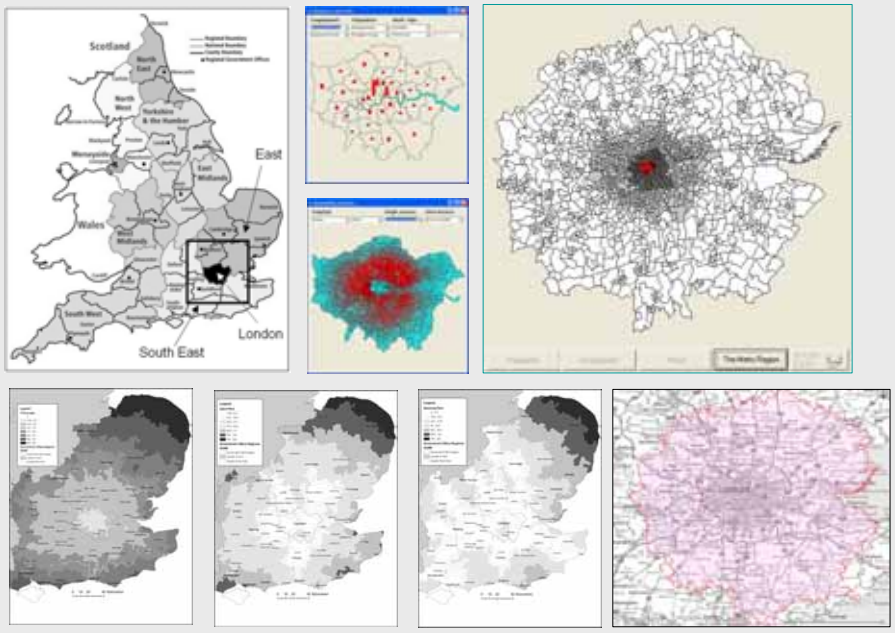




Scaling Up Urban Models



Scaling Up Urban Models



Applications

A New Retail Centre in Dubai

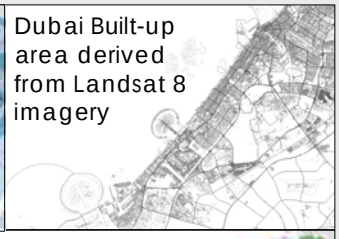


Where did we get the data – in a data poor environment?

Dubai Business Density derived from Google Places API

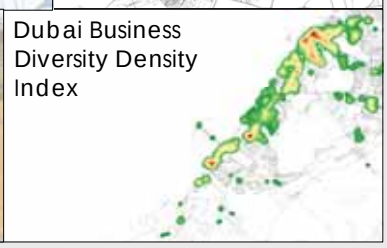


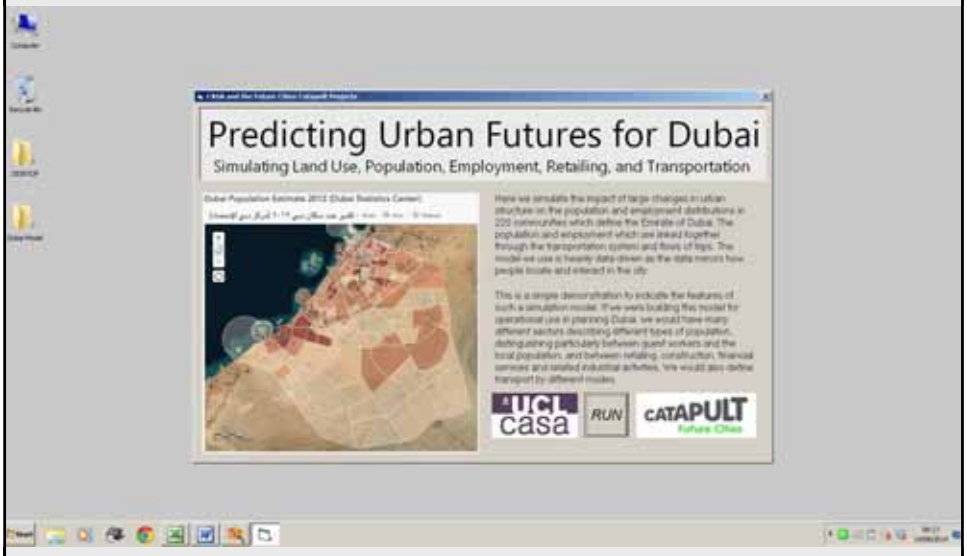
Dubai Built-up area derived from Landsat 8 imagery

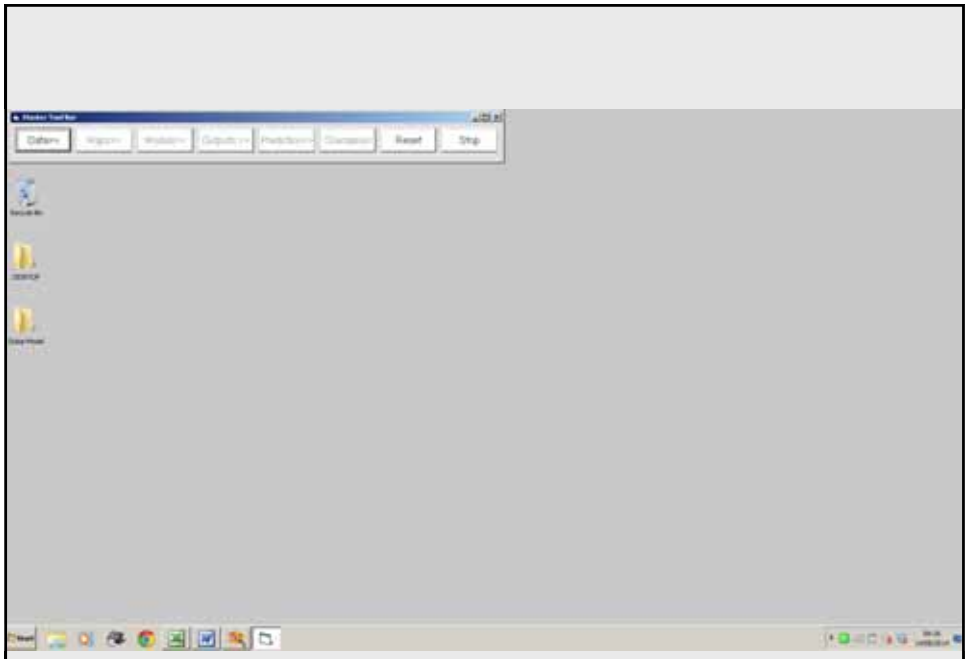




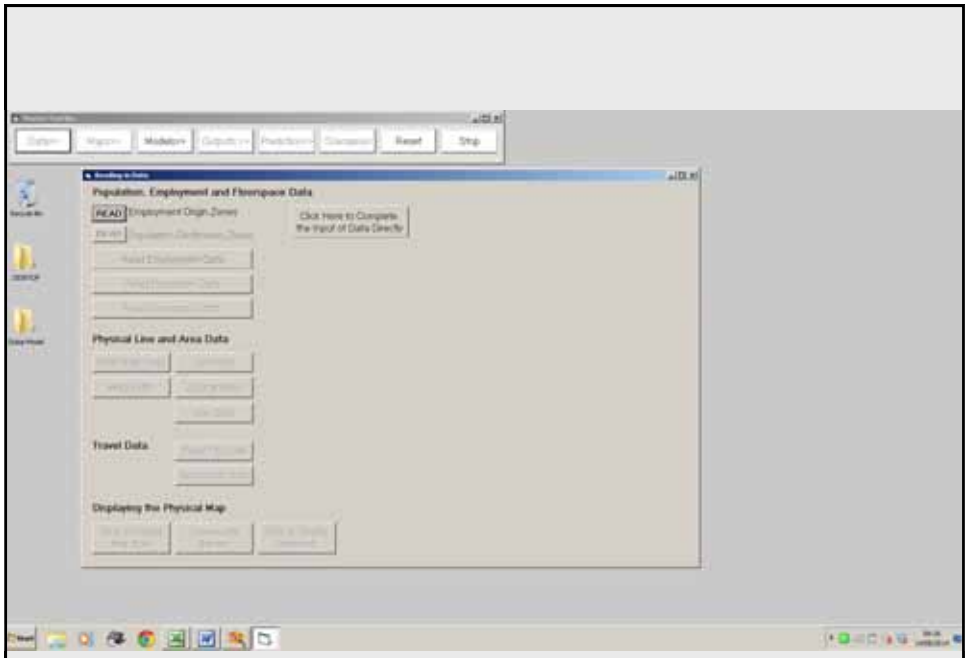
Dubai Business Diversity Density Index



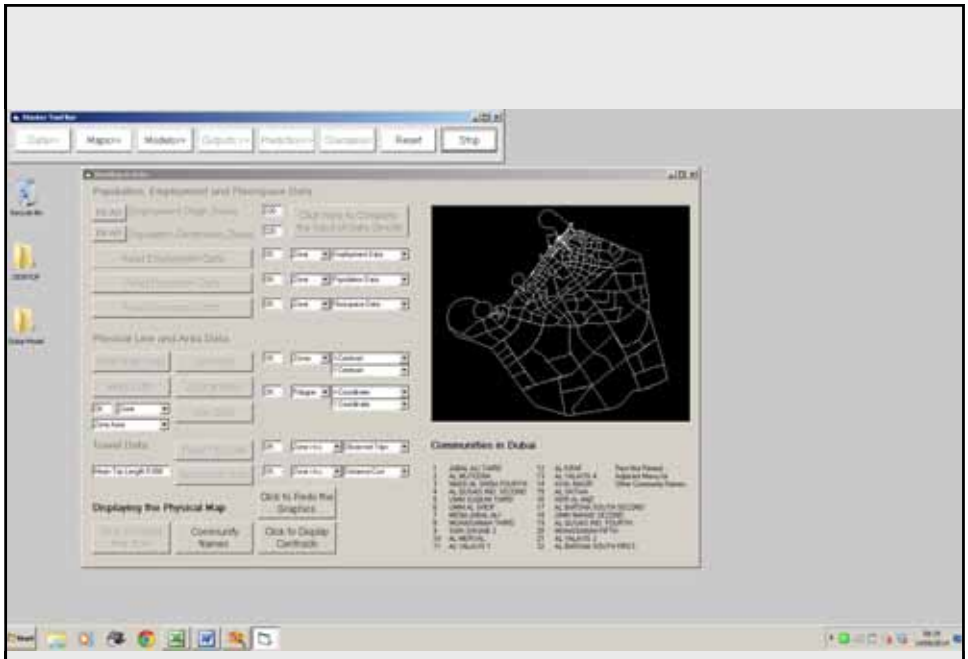




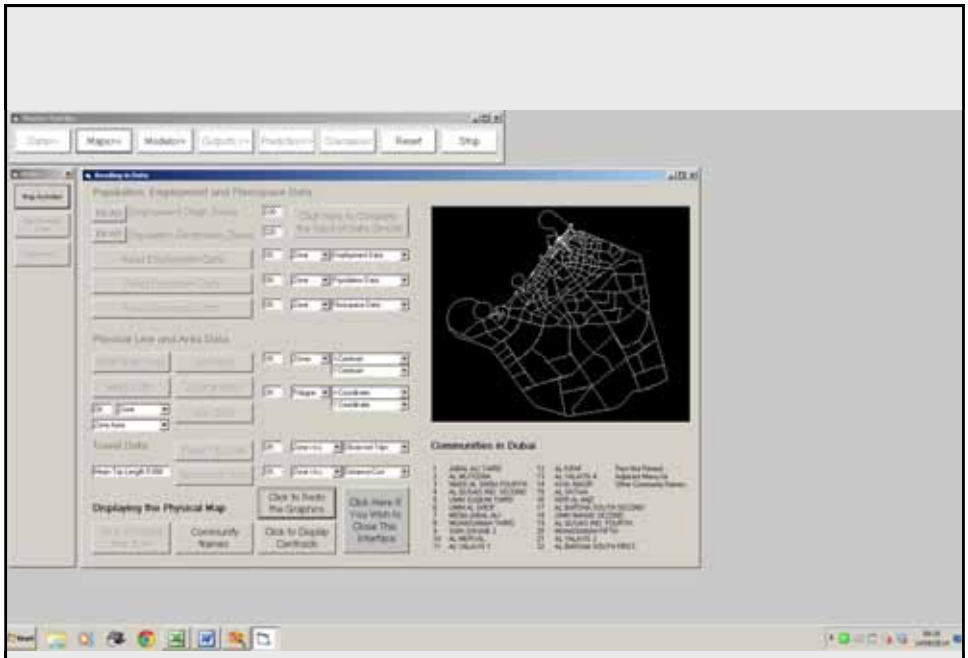
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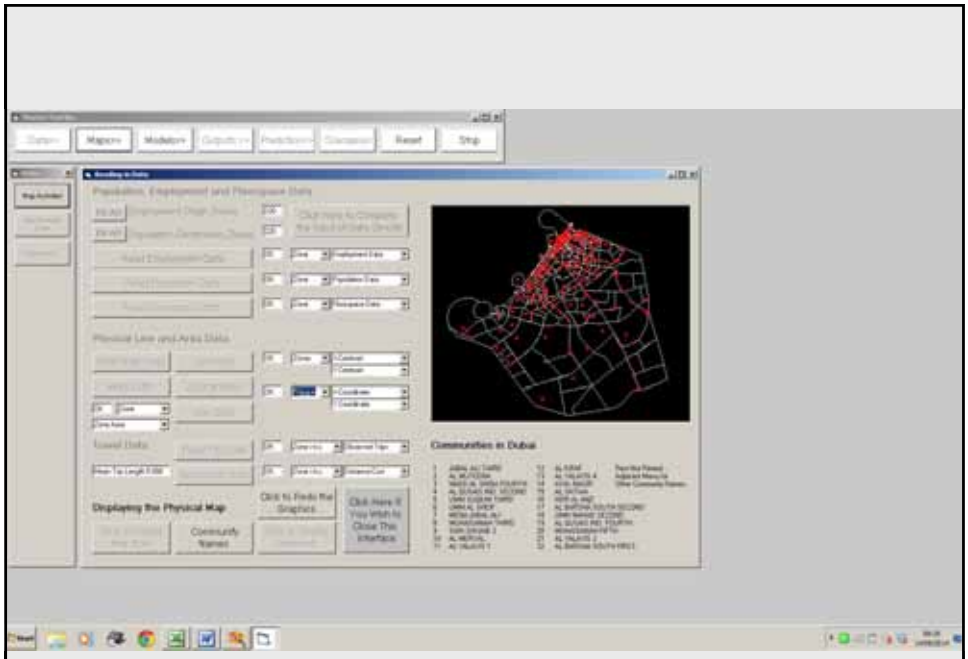
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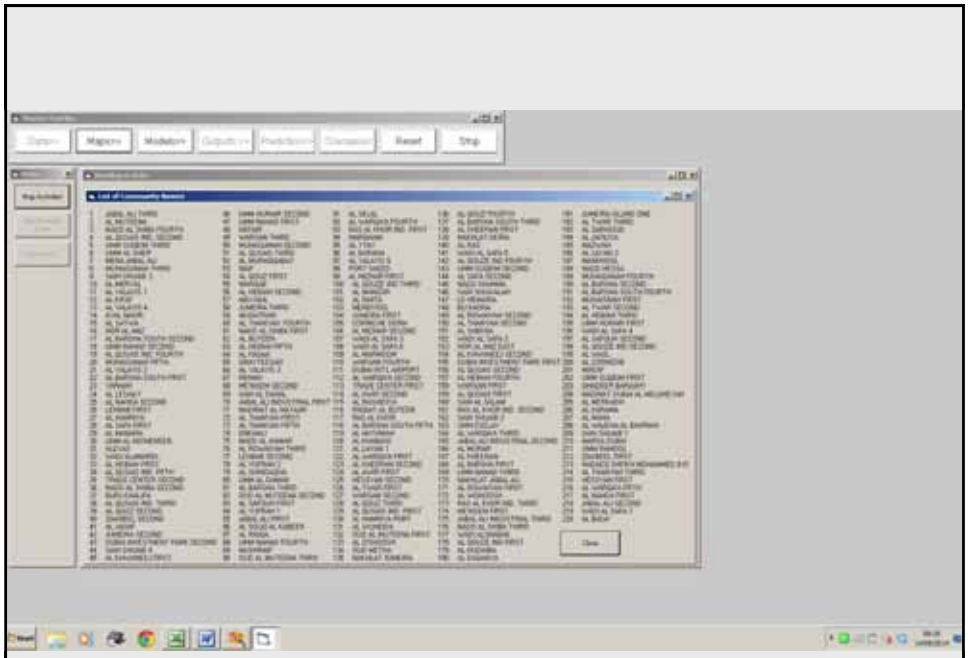
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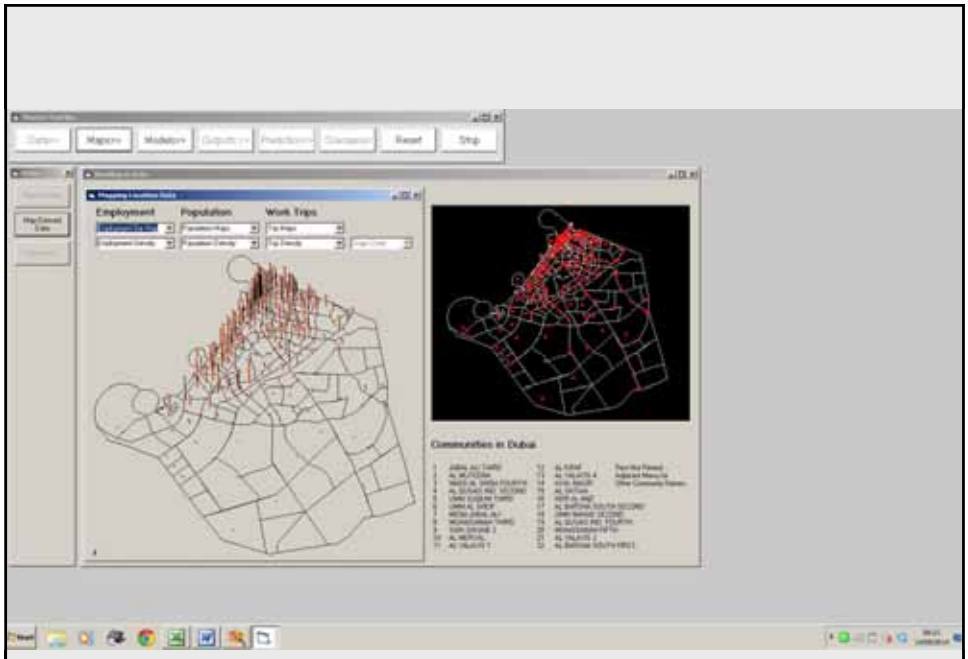
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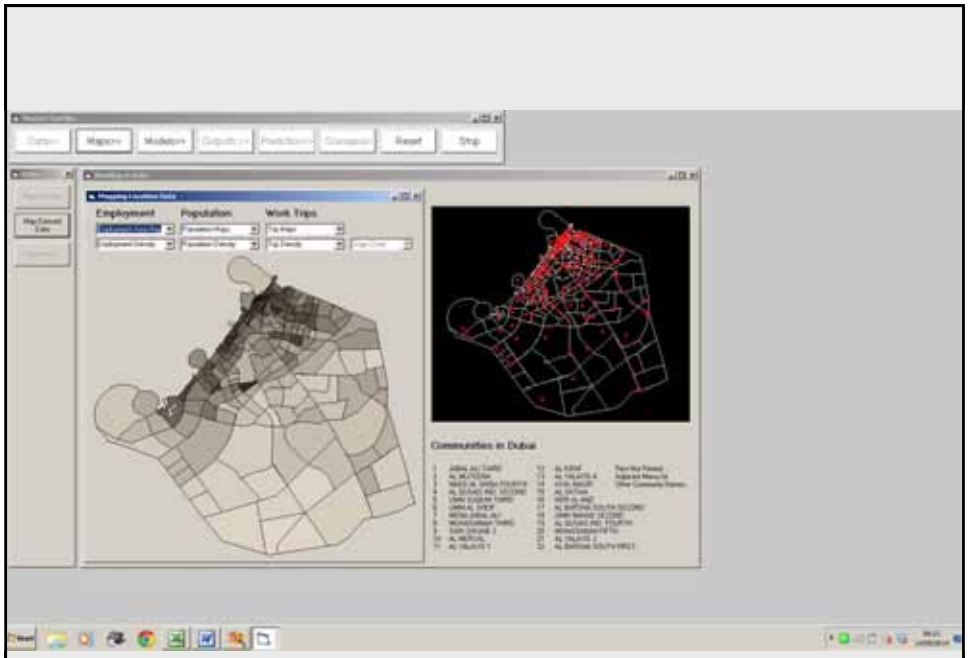
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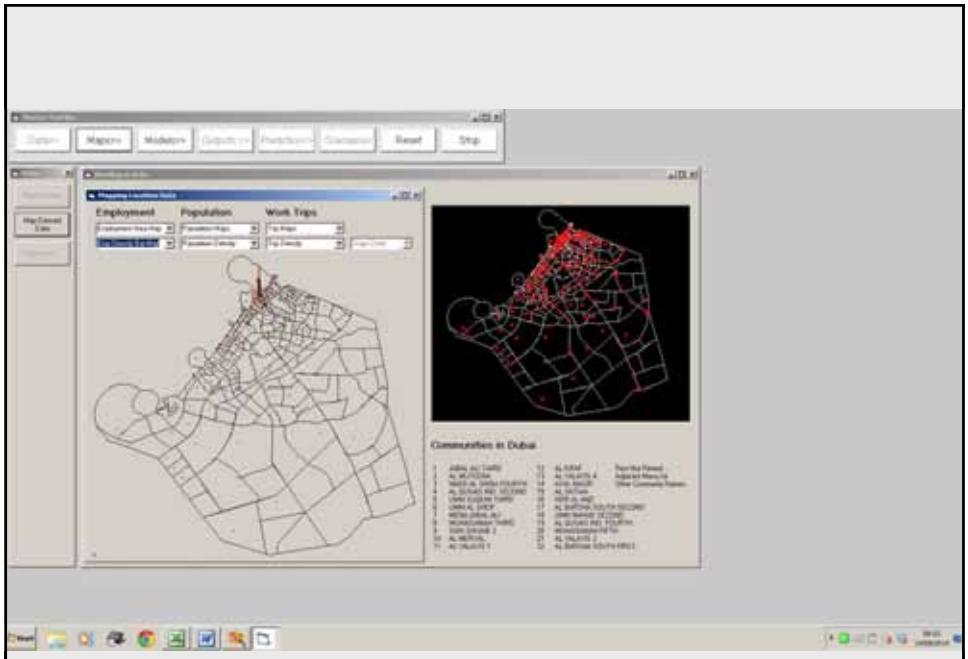
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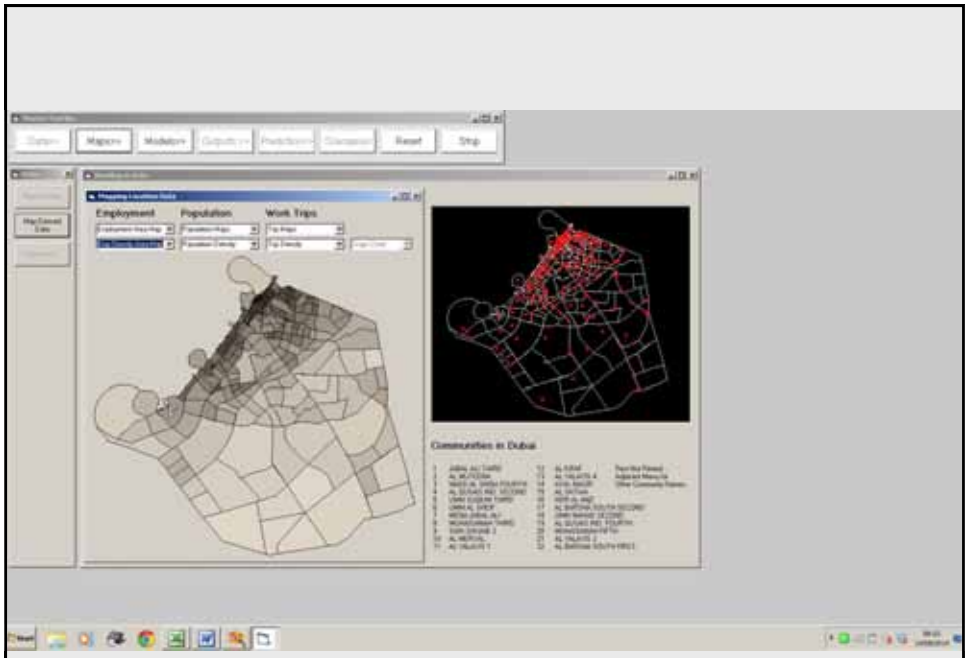
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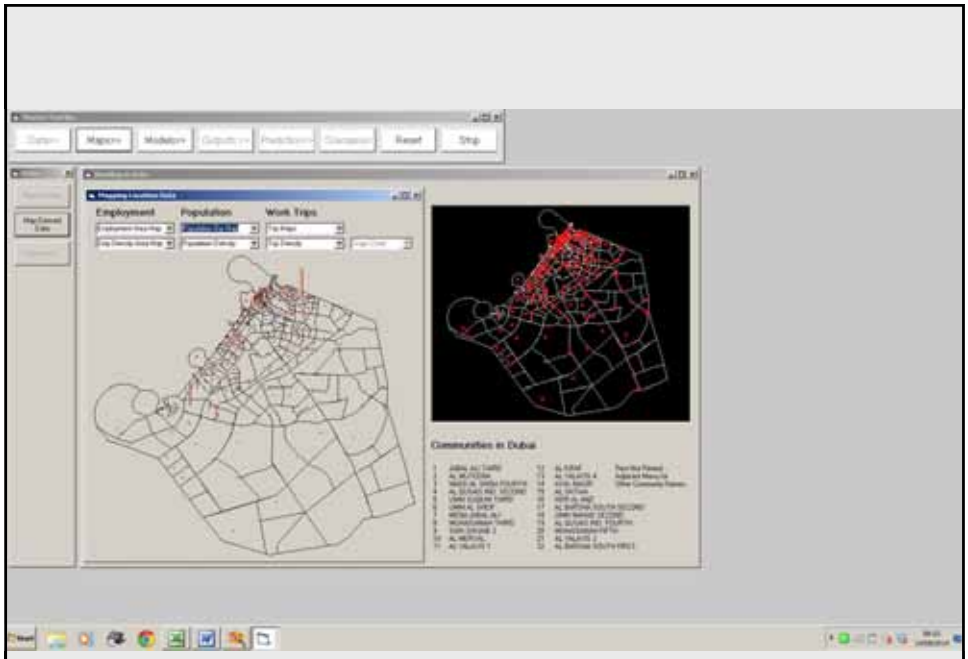
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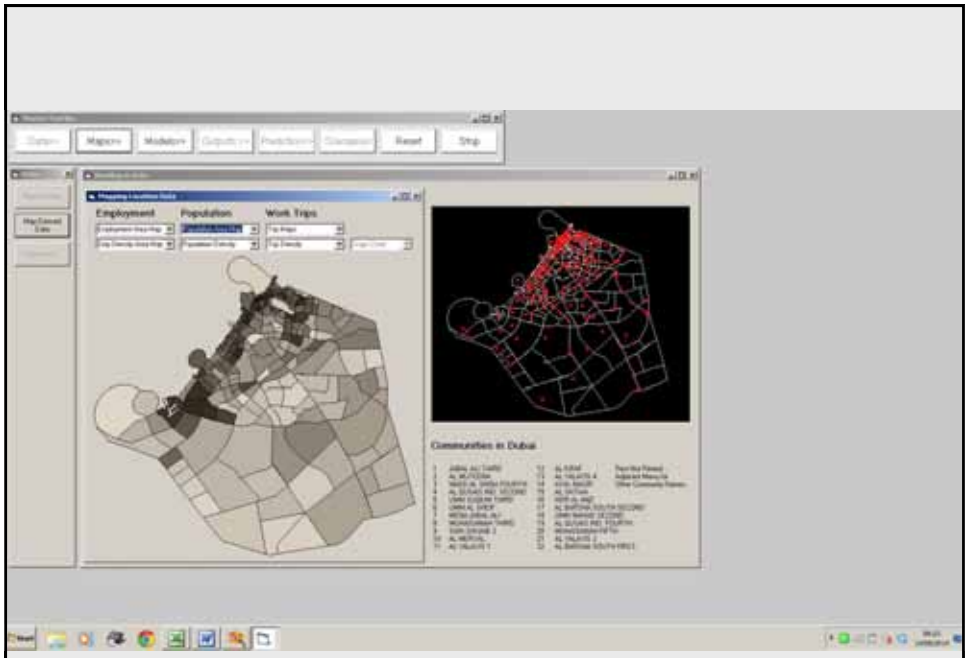
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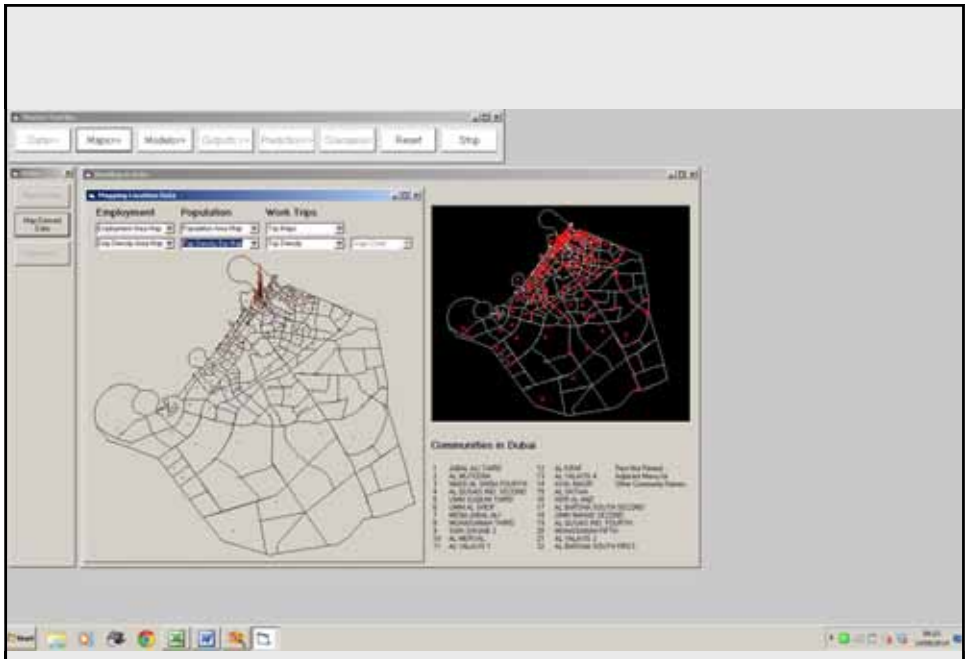
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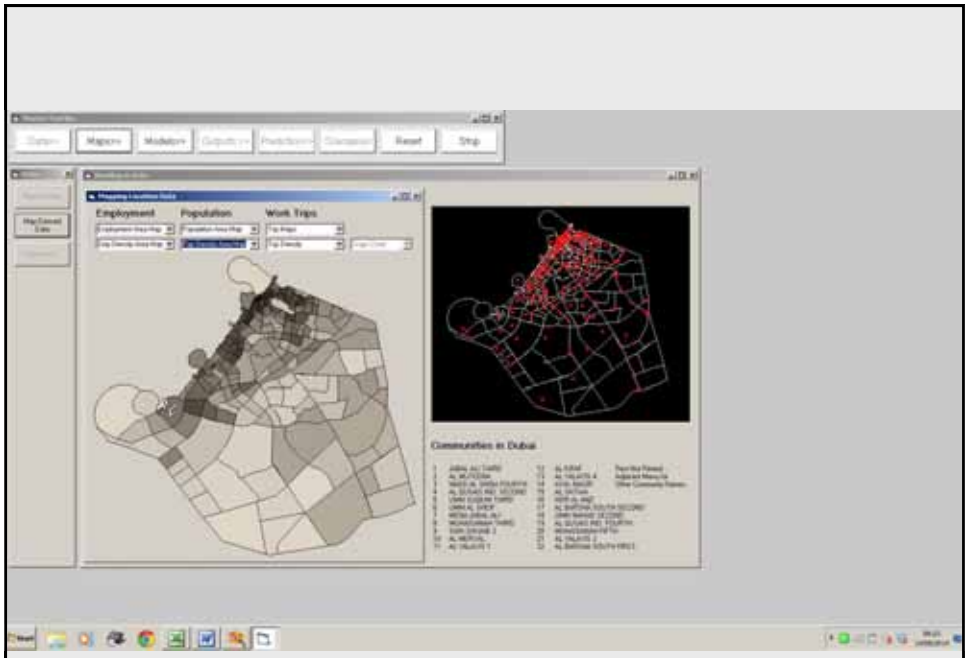
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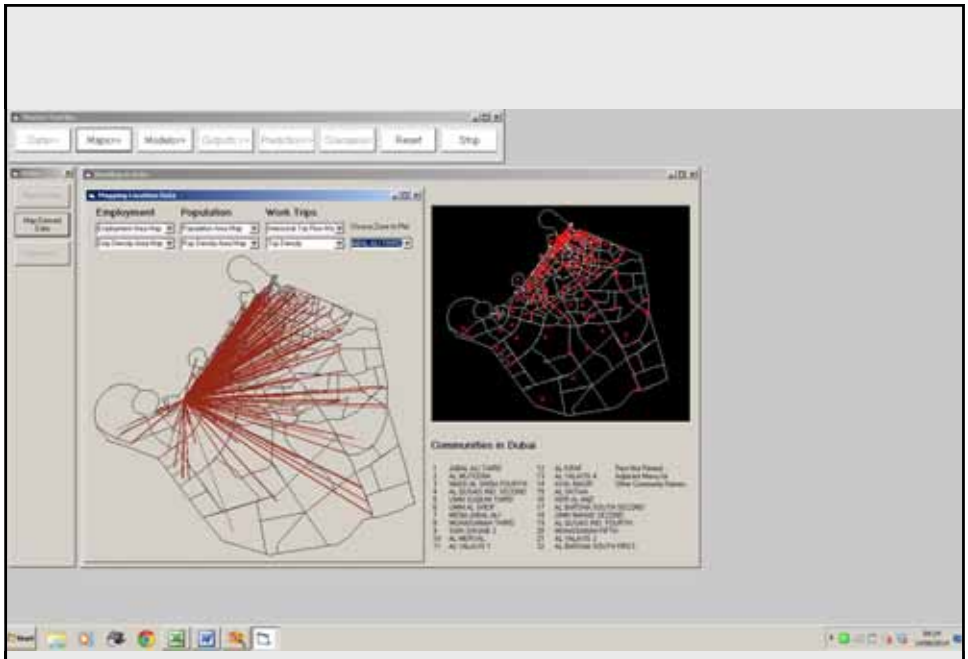
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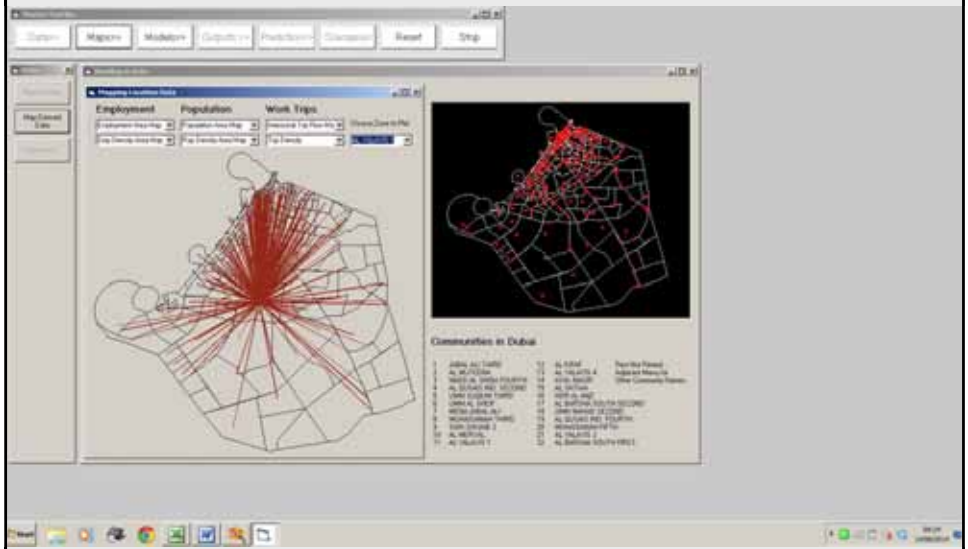
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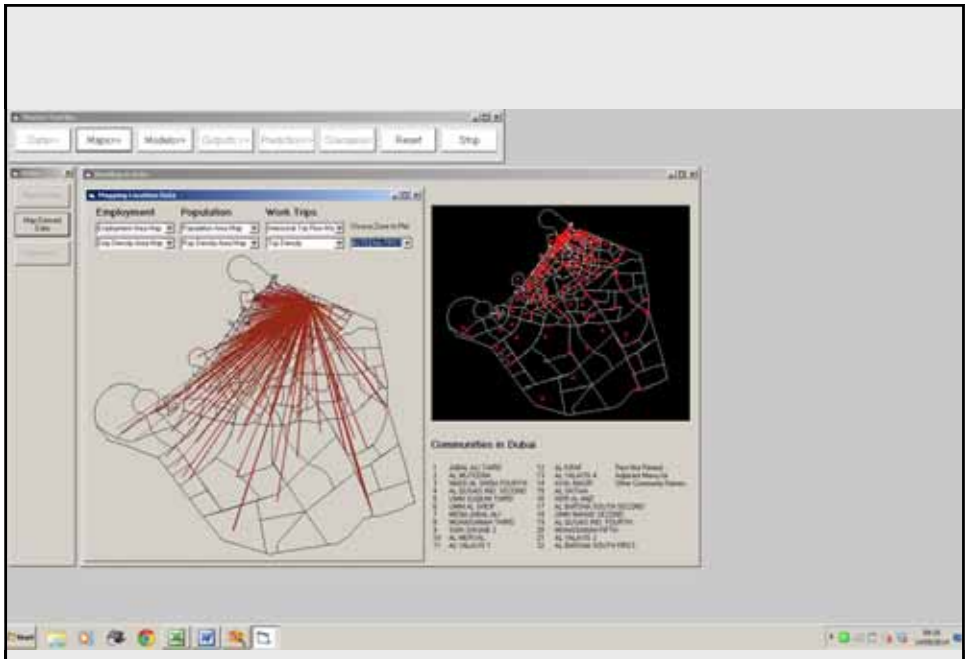
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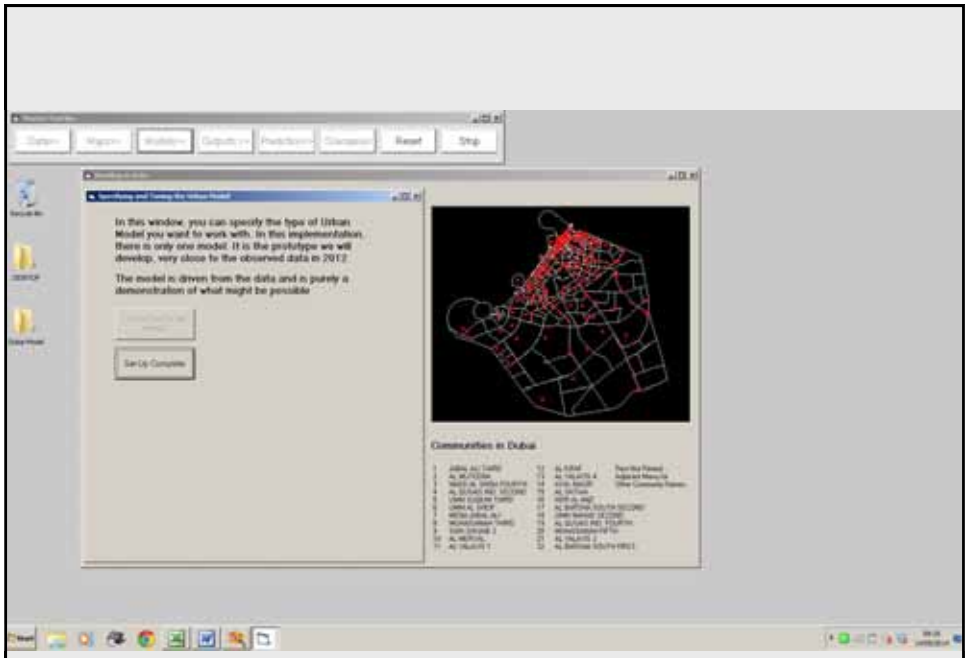
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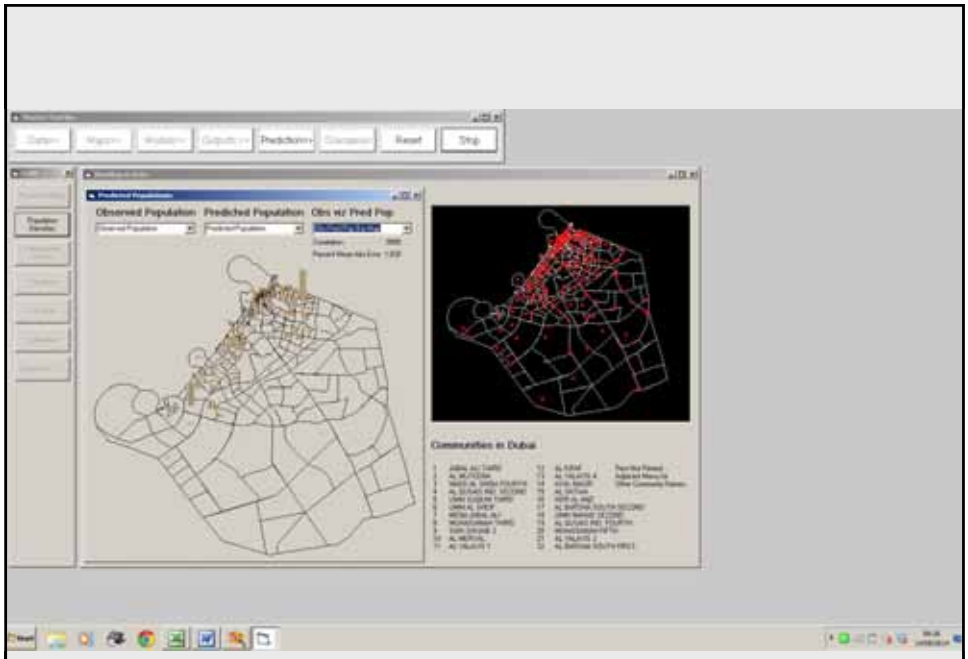
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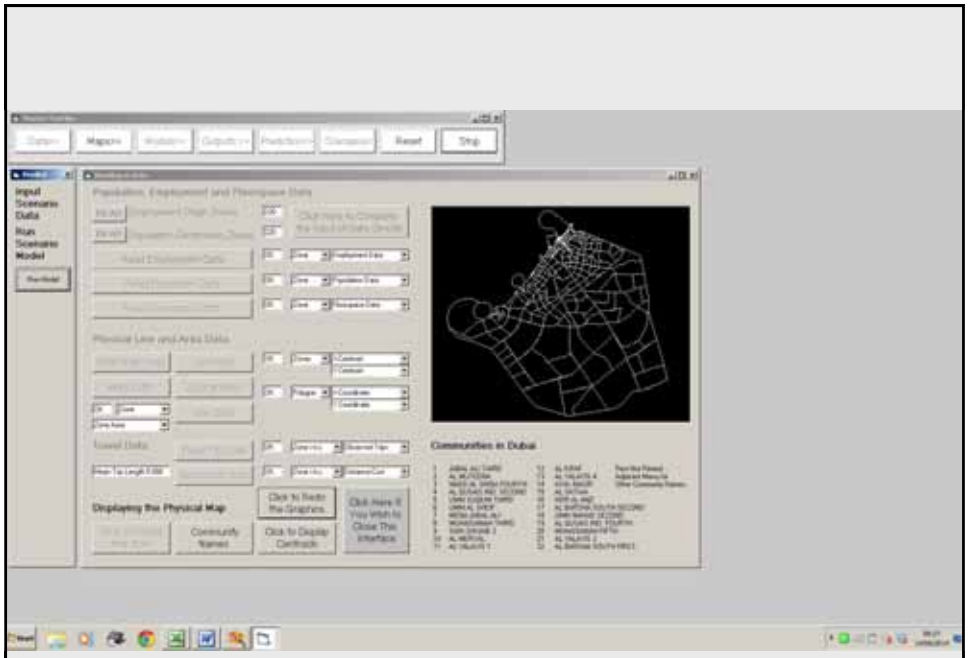
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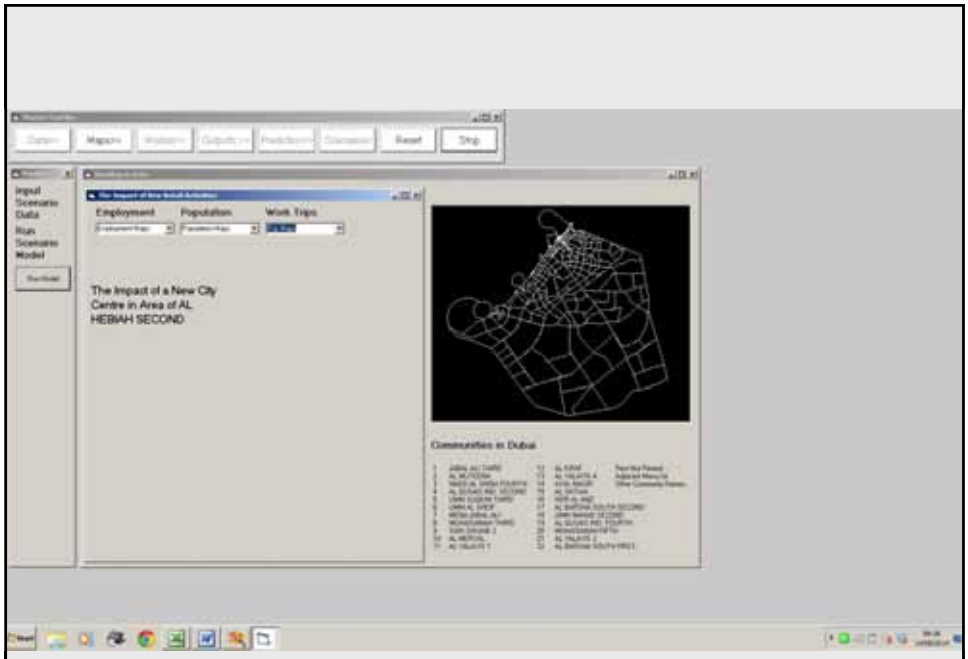
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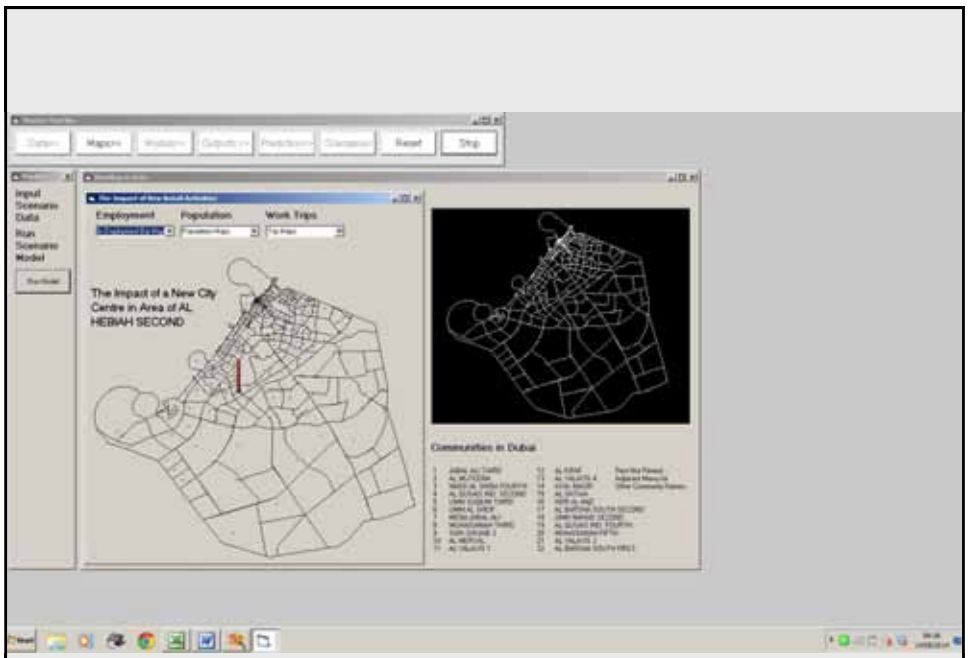
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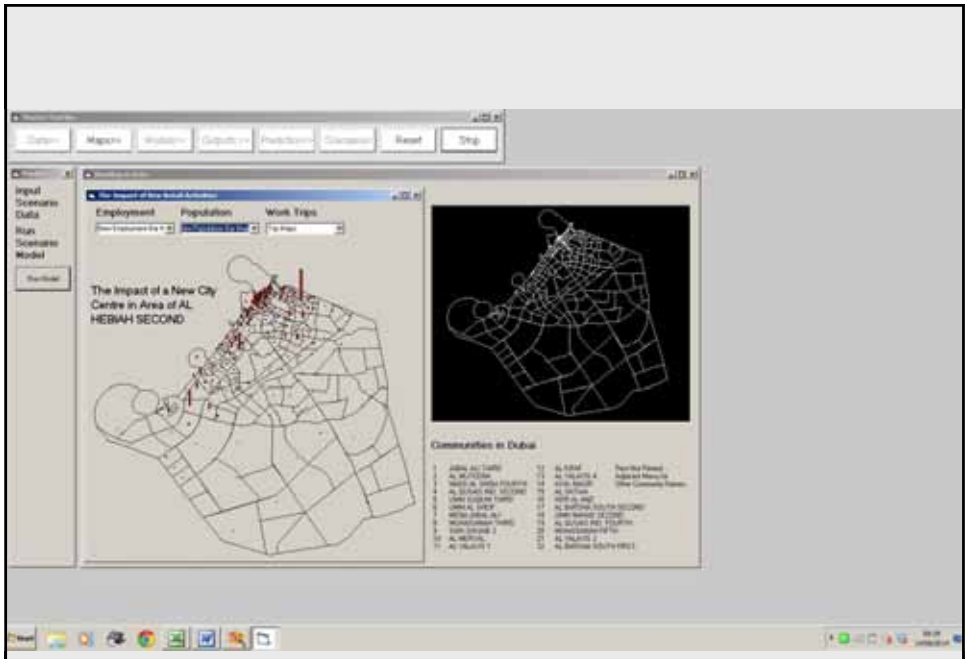
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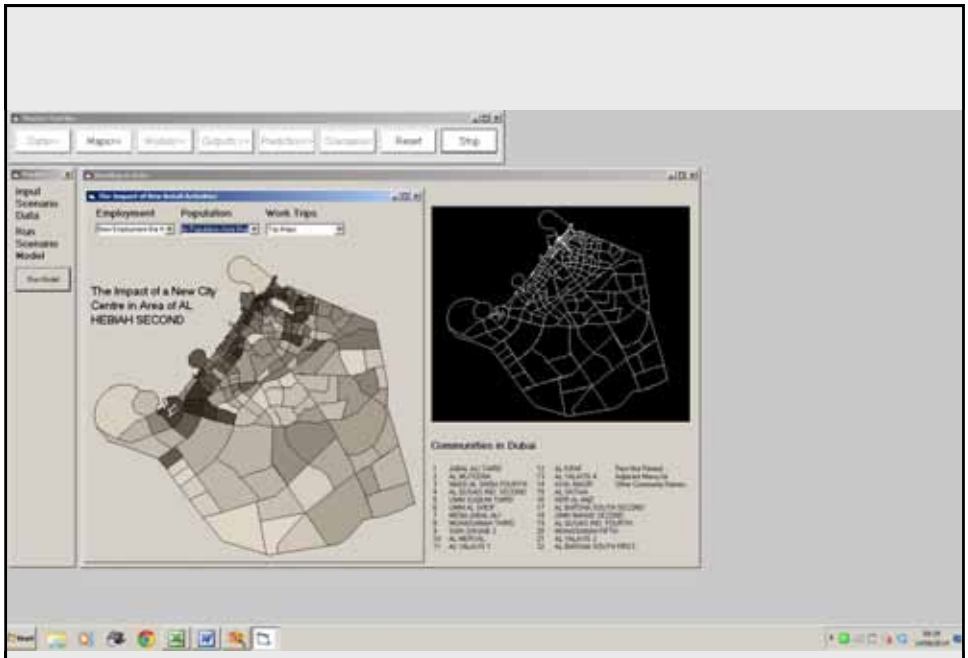
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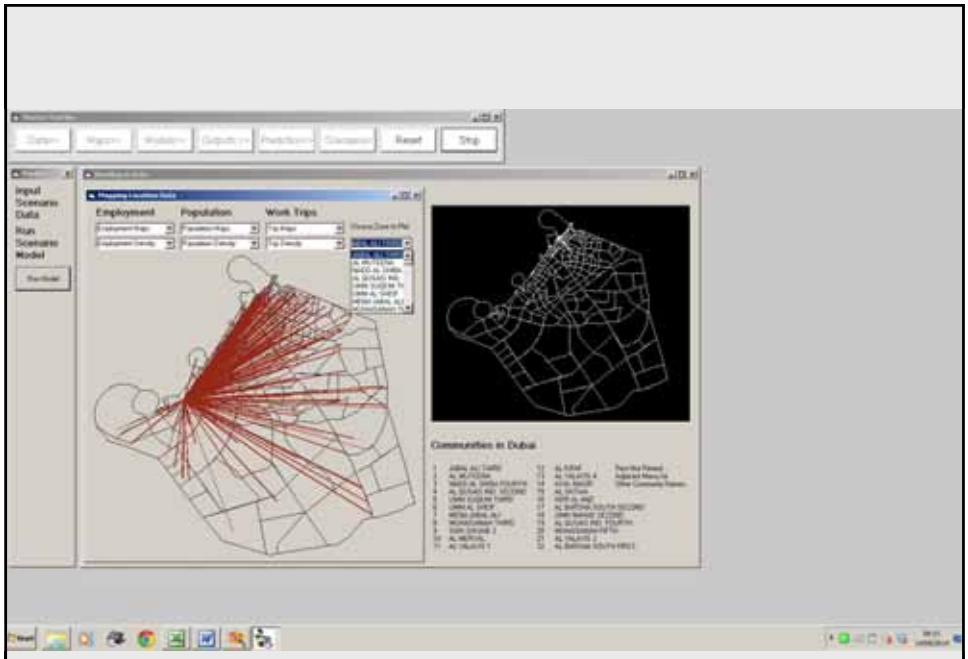
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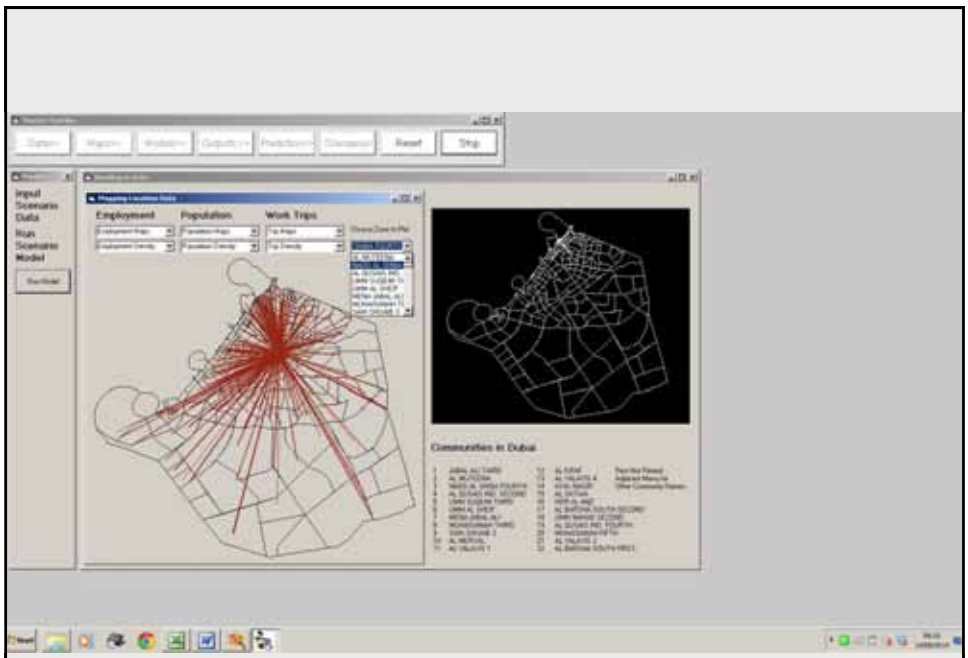
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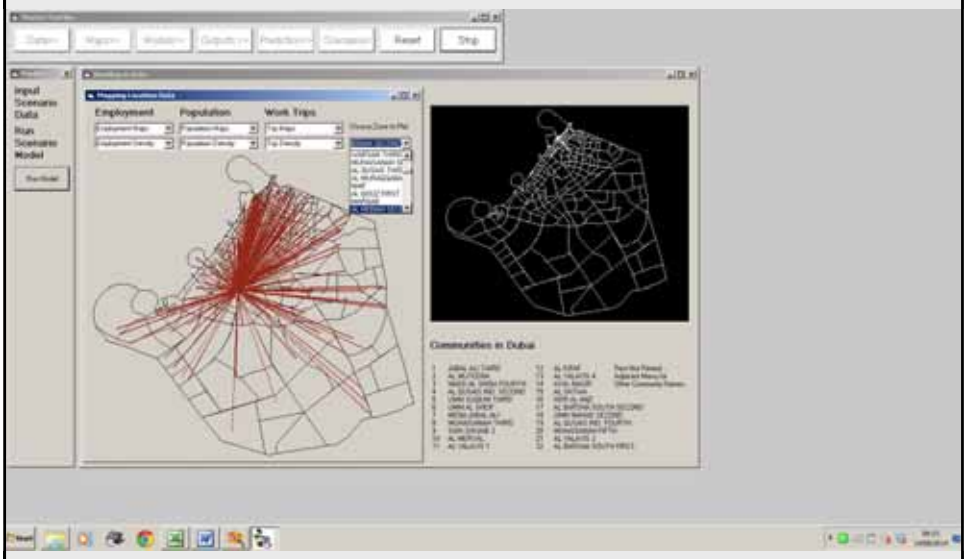
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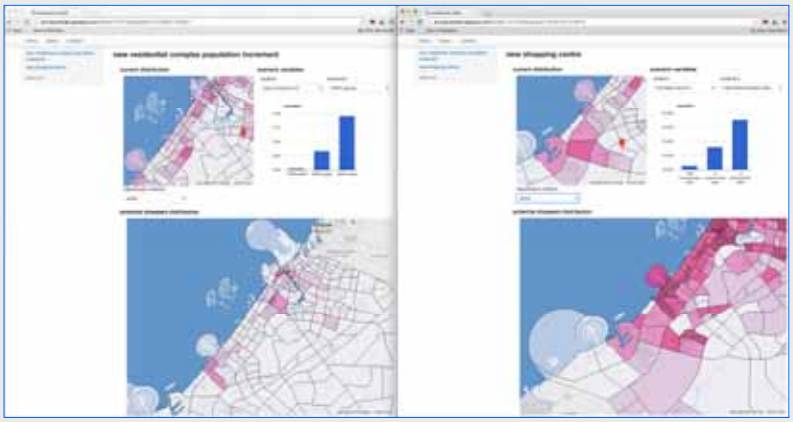


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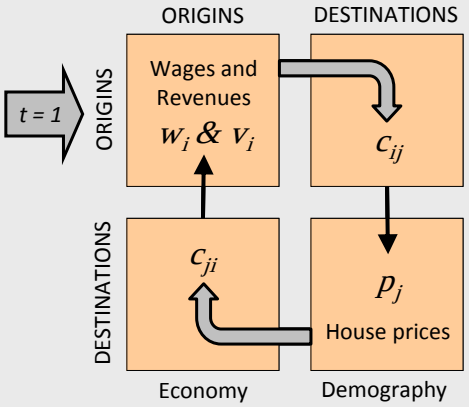
Applications

A New Retail Centre in Dubai

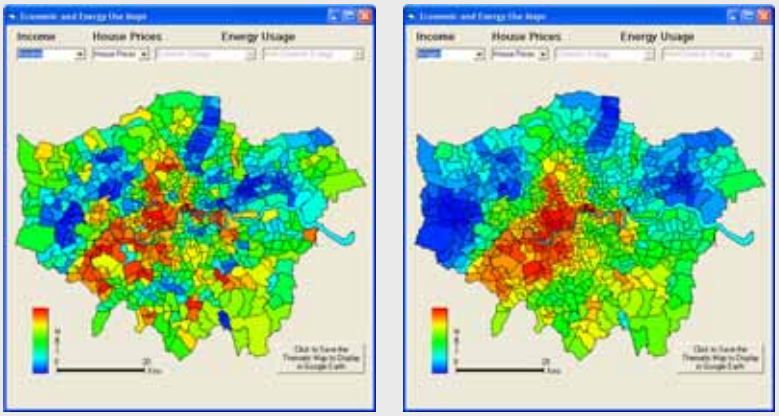


New Models: Money Flows, Hierarchical-Multilevel, Data Driven, …

Our current model is more disaggregate, more extensive and is really a suite of model types, it has an explicit money sector as house prices and wages are quite important. We do not attempt to model markets



To illustrate very briefly the sort of data that we have in the money sector that is driving this variant of the model and also the residential location equations



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).



Two major areas of our research are to extend our spatial interaction models to multilevel systems – nested hierarchies or even overlapping hierarchies. This is to ensure that where we have data at different levels we can constrain the model to meet these data if required.

An example is that we want to make our model consistent with another national model – LUISA – built by Ying Jin and Li Wan at Cambridge UK (Echenique stable) and that works at a much more aggregate spatial scale but much more disaggregate topical scale

And we also want to use data to drive our models – to use Fratar like biproportional factoring of data as our focus is often on short term immediate predictions

QUANT: Building a Web-Based Model Interface

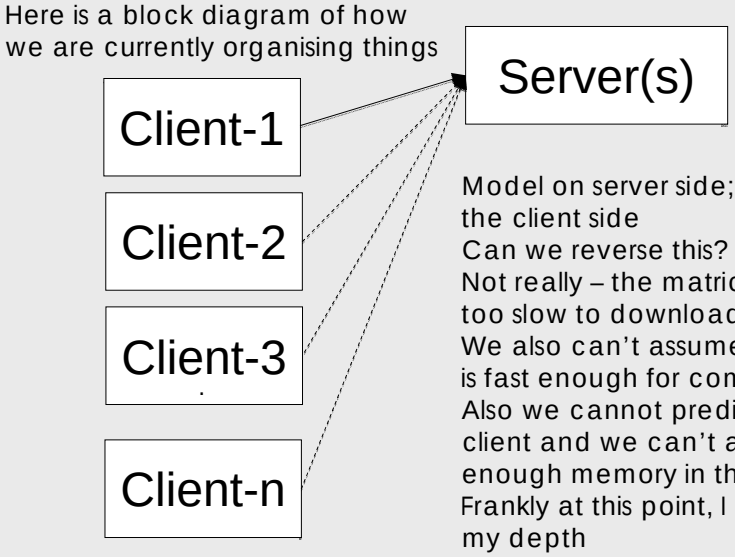
We are building this aggregate LUTI model of the UK – well E&W at present – we will add Scotland before long – which is of the nature we have been implying

Without going into details, the model takes a few seconds to run – it will take a lot longer when finished as we will add sectors and of course the number of big data we have to hold in RAM might be very large – currently we need to hold 3 x 2 = 6 52 million sized matrices –

we may need to go up to multiples of this and that will involve a lot of packing and moving in and out of core, I think

The Web and the Desktop: Users are also Data

Here is a block diagram of how we are currently organising things



Model on server side; Maps on the client side
Can we reverse this?
Not really – the matrices are too slow to download to client?
We also can't assume the client is fast enough for computation.
Also we cannot predict the client and we can't assume enough memory in the client
Frankly at this point, I am out of my depth

So Let Me Give You A Demo Of What We Are Doing
If I can depending on the web link and my VPN

The web link is

http://quant.casa.ucl.ac.uk/

For those who want to try it out

There is always ***a caveat emptor*** with demo models like this. We are building it as a demo for the FCC and it not supposed to be a flashy app or anything – it is something that local authority planners and consultants might use as a resource along with many other complementary decision support tools



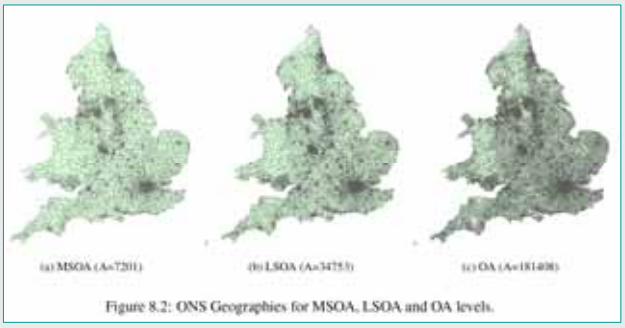
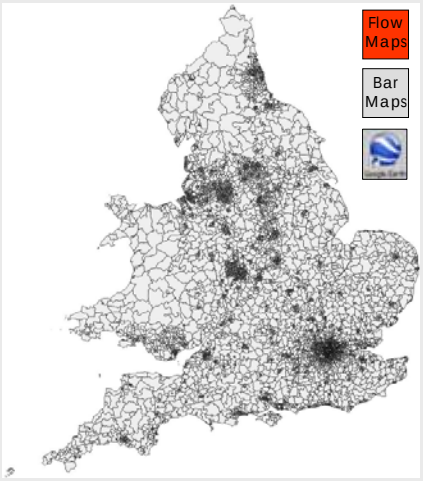


Figure 8.2: ONS Geographies for MSOA, LSOA and OA levels.



Scaling Up Urban Models





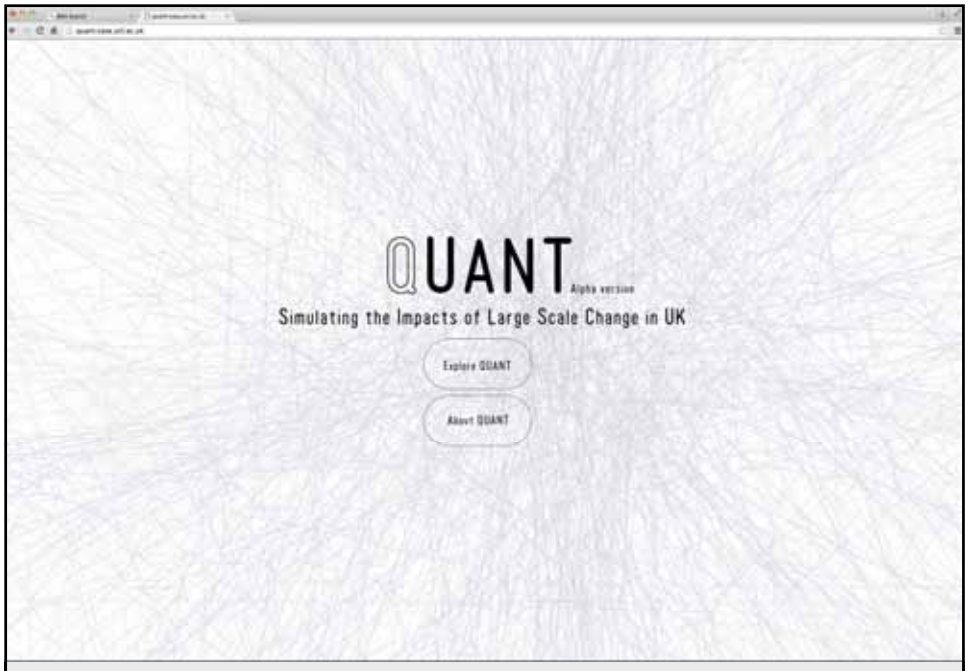
$$[x_i, y_i] = [[x_i, y_i], \left[\left[x_i + \frac{\sum_j T_{ij}[x_i - x_j]}{n}\right], \left[y_i + \frac{\sum_j T_{ij}[y_i - yy_j]}{n}\right]\right]$$

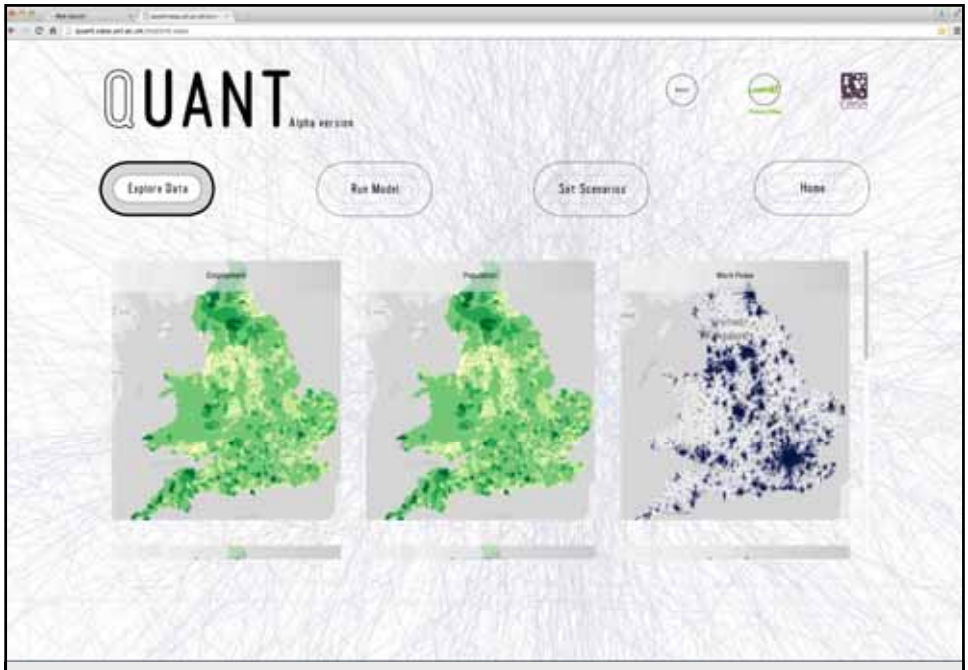
Scaling Up Urban Models

The QUANT Model: For Very Large Areas

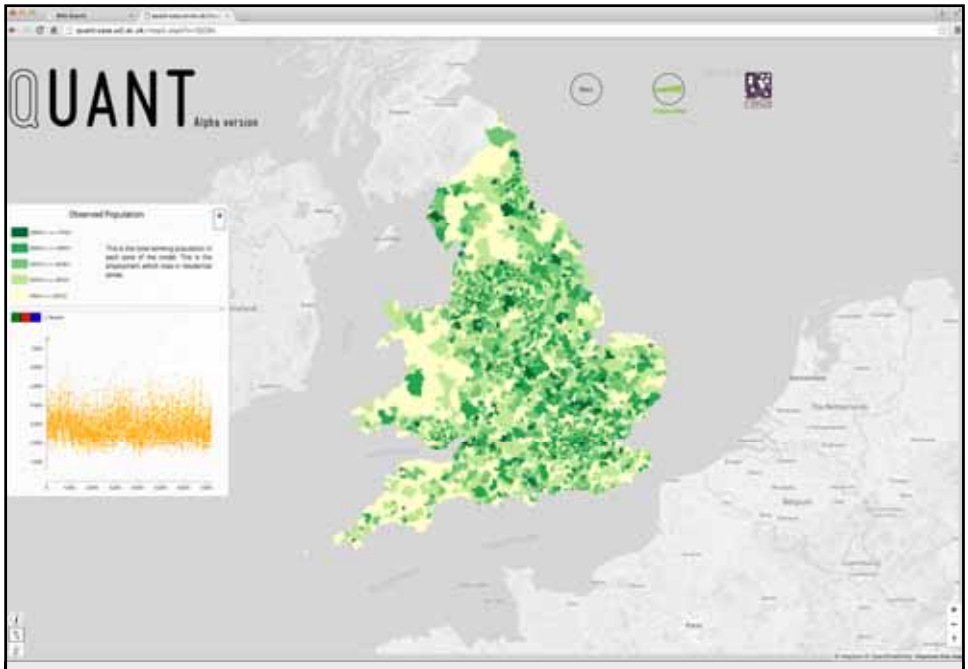
Now what happens when we really do scale up to the level of MSOAs of which there are 7201 in the UK – do we partition the spatial system and argue we don't need to scale up to $n^2=7201^2=51,854,401$?

Circa 52 million points is an issue but our models run in a matter of seconds but that is a lot of data to store – ok it is sparse but sparsity isn't structured so we can't easily partition and in any case we want to compute any possible flow e.g. between, say central London and say Newcastle. Here is the problem scaled up and this is what we are grappling with at present.

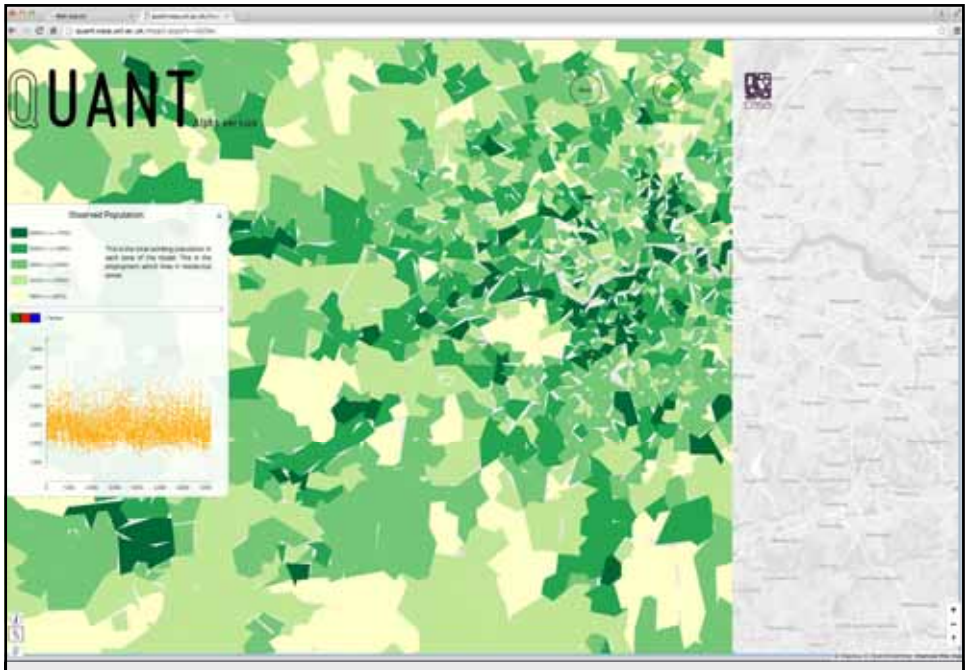




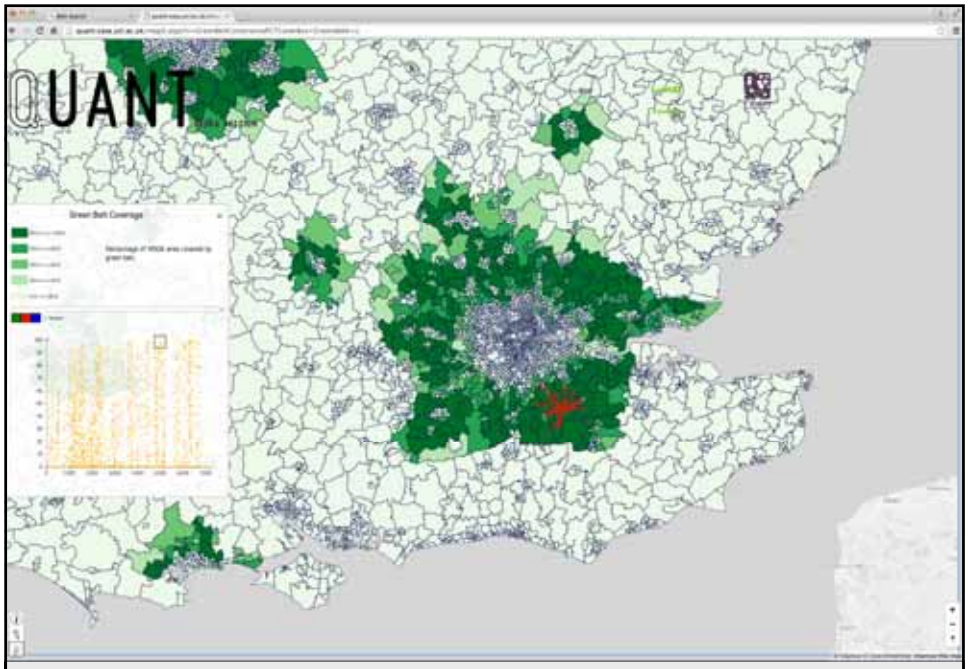
Scaling Up Urban Models



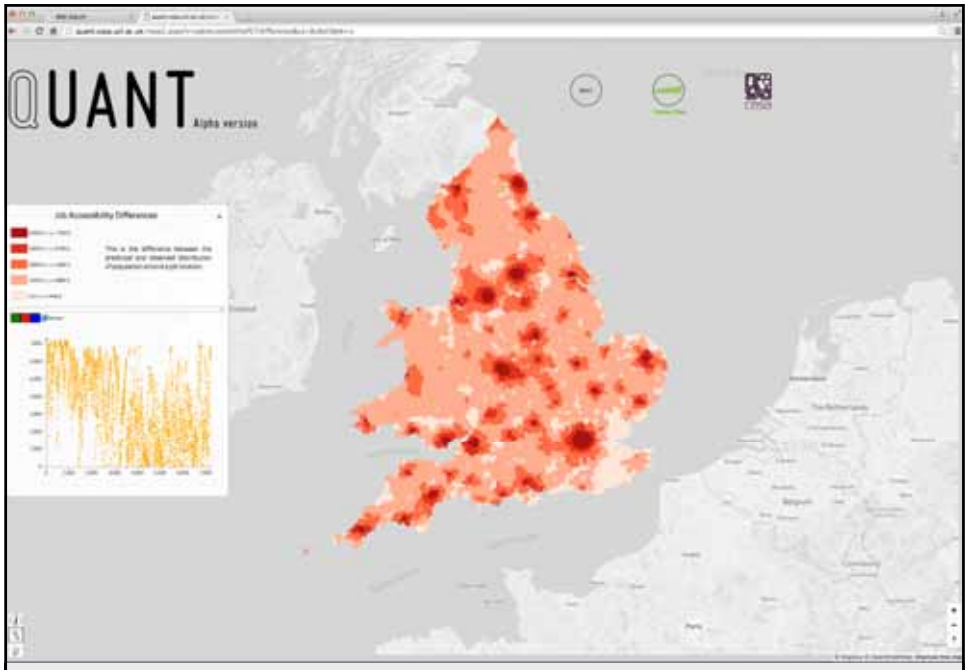
Scaling Up Urban Models



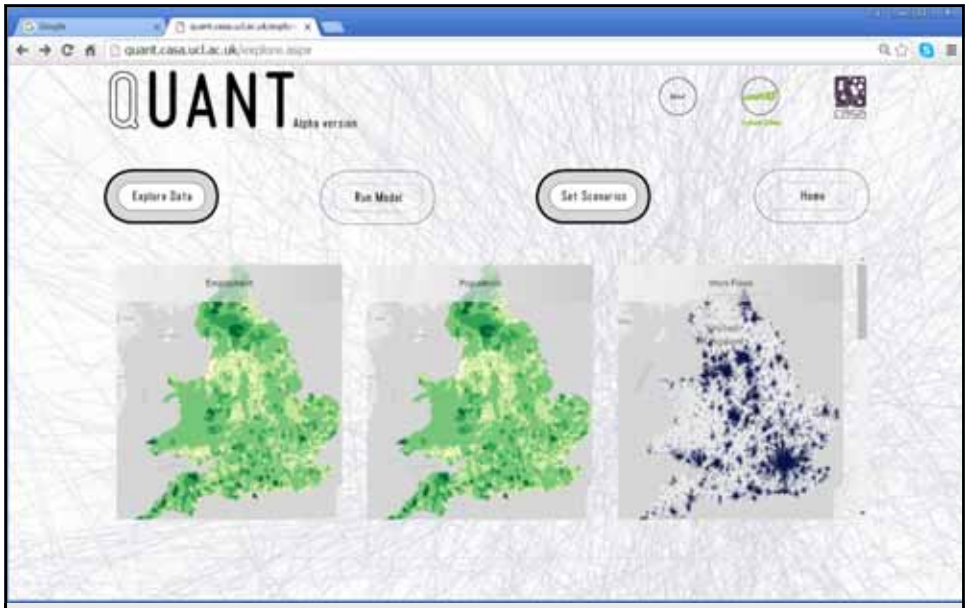
Scaling Up Urban Models



Scaling Up Urban Models



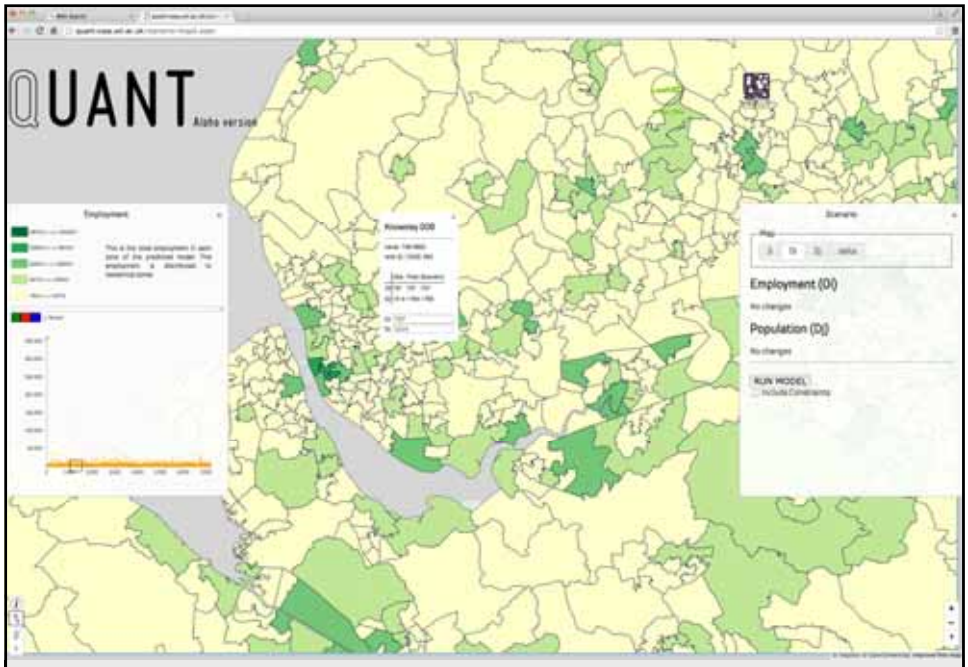
Scaling Up Urban Models



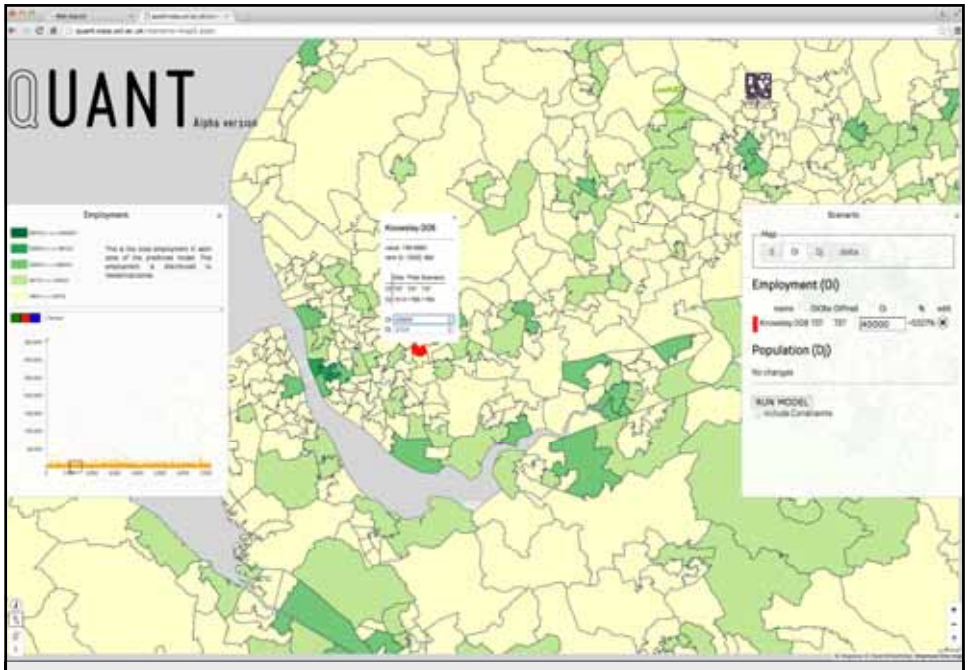
Scaling Up Urban Models



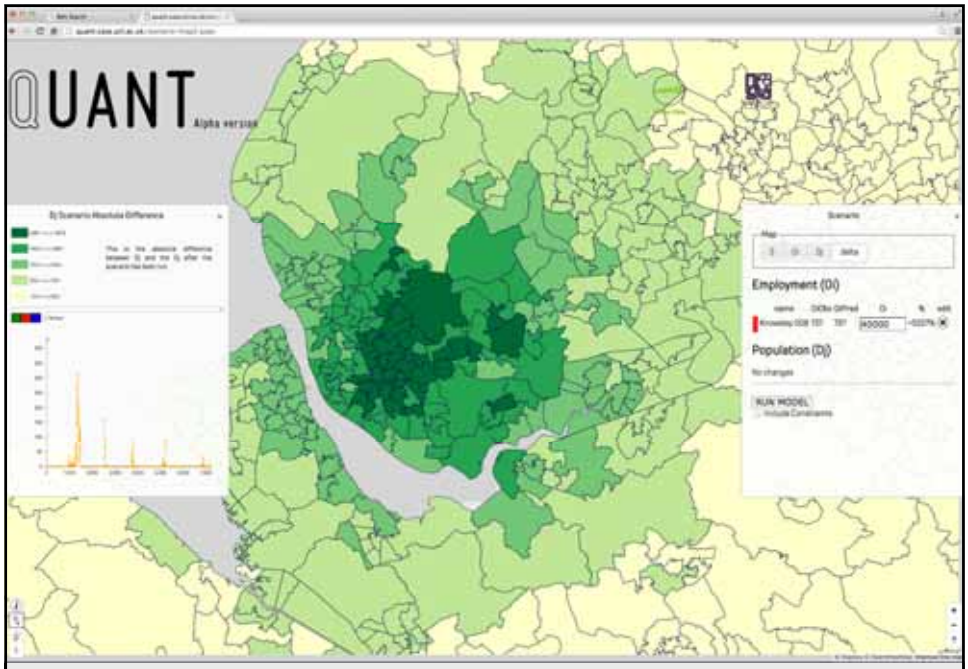
Scaling Up Urban Models



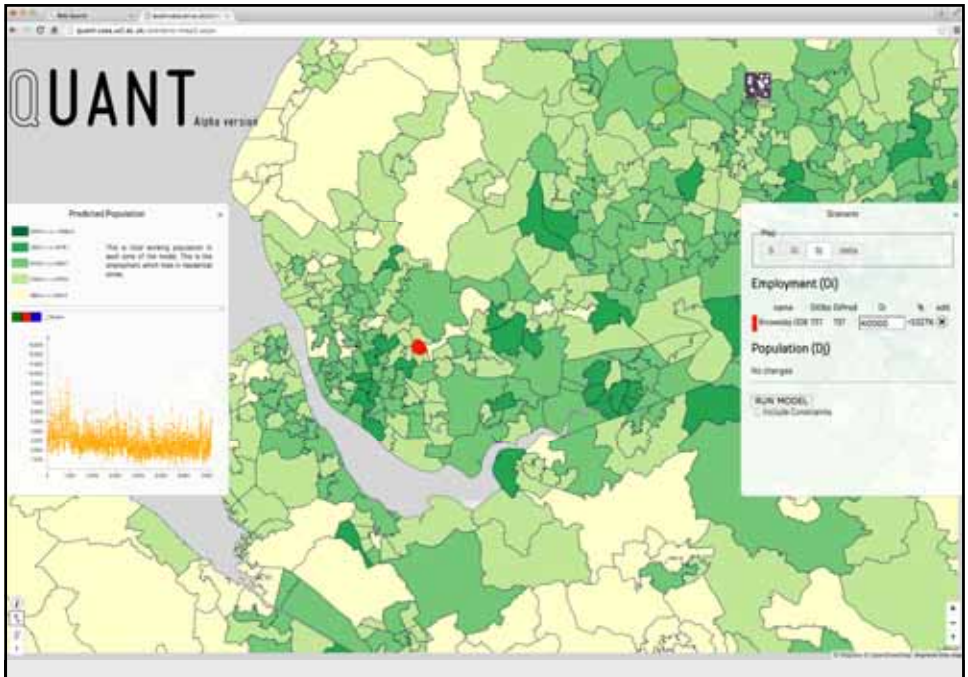
Scaling Up Urban Models



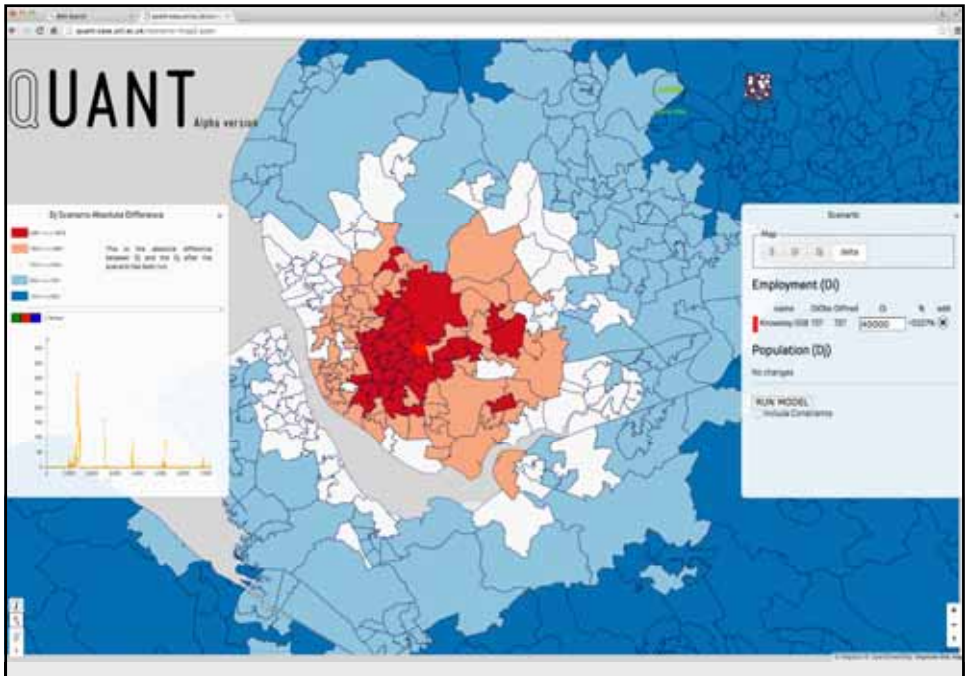
Scaling Up Urban Models



Scaling Up Urban Models



Scaling Up Urban Models



Scaling Up Urban Models

Transport Networks



Road, v=3.5M, e=8.4M

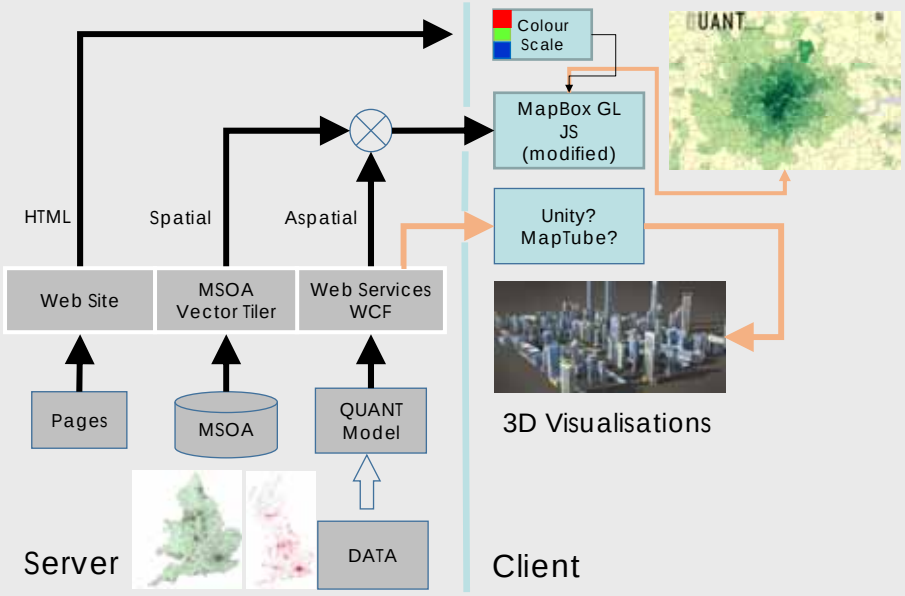


Bus, Ferry, v=0.29M, e=0.42M



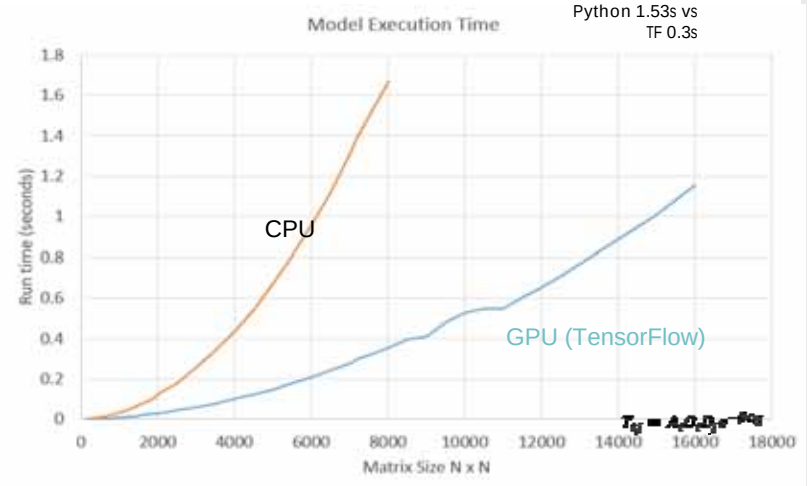
Rail, v=3165, e=10,269

Client & Server Architecture



Benchmarking Urban Models

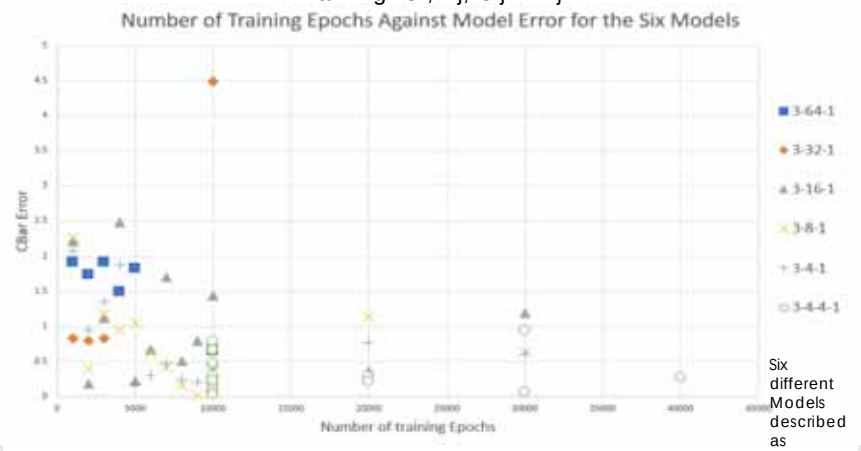
C# 1.22s vs
Python 1.53s vs
TF 0.3s



QUANT Model Run Time by Matrix Size

Neural Spatial Interaction Models

Training: Oi, Dj, Cij → Tij



Six different Models described as Inputs-Hiddens Outputs

Inference time varies between 74s (CPU) and 1.156s (GPU) for the 3-64-1 model down to 2.15s (CPU) and 0.93s (GPU) for 3-4-1

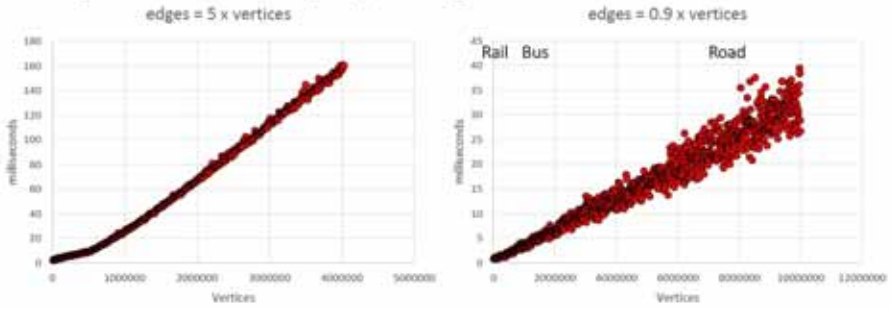
Networks: Single Source Shortest Paths

GPU test on shortest path modification



GPU Shortest Paths (nvGraph)

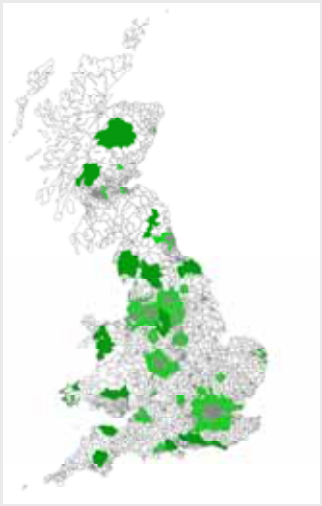
Single Source Shortest Path (SSSP) test using random networks

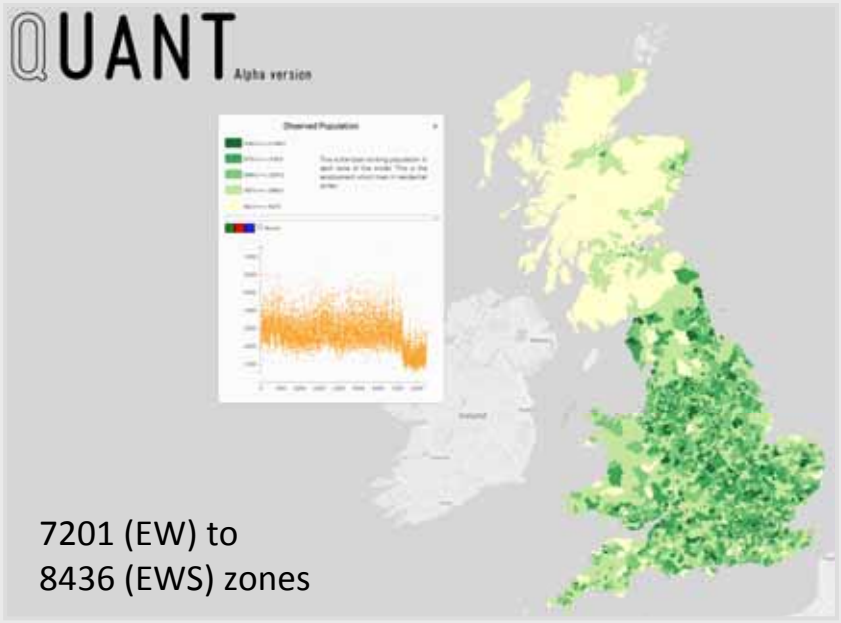


To add Scotland, we need a Great Britain OD Matrix
<u>BUT</u>
Different Census
No MSOA but IZ

We also are adding other layers – AONB etc.

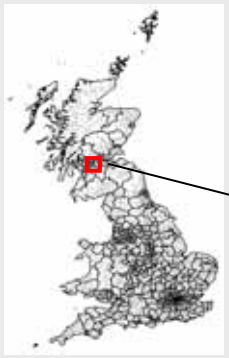






Extending the Model Hierachies

Local Area Glasgow City – 133 MSOA
Dwelling Population 2011 ~290,00 / 2031 ~295,000





1. Redistribute values – Prorated
2. Extended model

Building Scenarios: Testing Large Scale Urban Impacts

I will illustrate some examples to give you a quick Idea of what is possible for sketch planning

Large Scale Railway Lines – Cross Rail and HS2

Green Belts and Airport Expansion

Local Scale Railway lines

CAMCOX Corridor

Crossrail

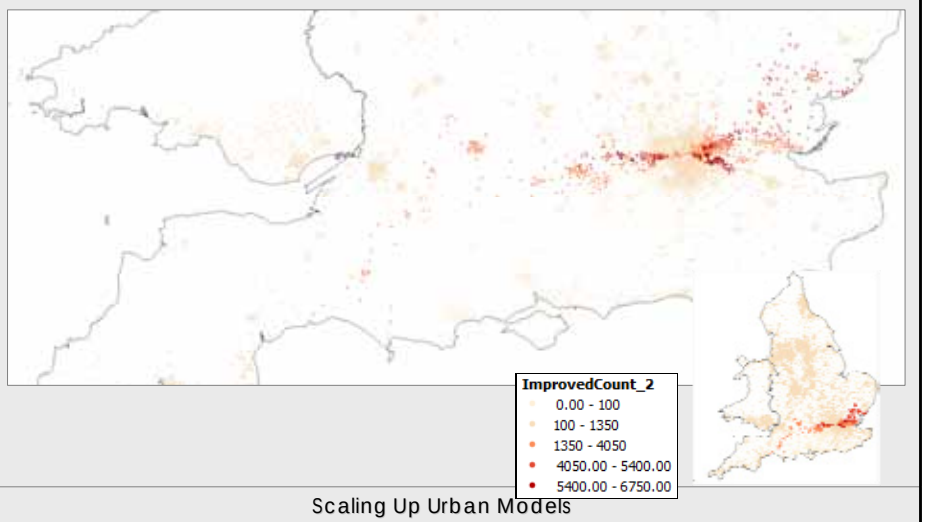
Reading, Heathrow, Shenfield, Abbey Wood





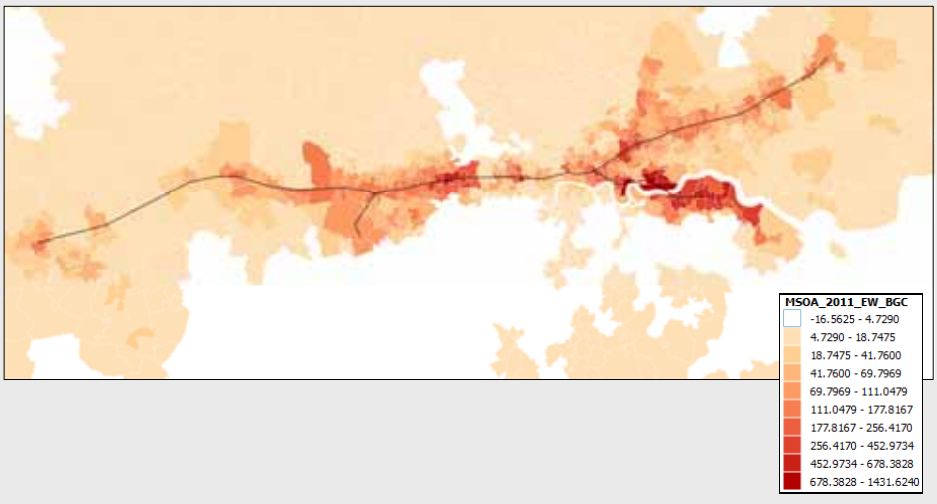
Crossrail

Number of Improved Journeys (ni)



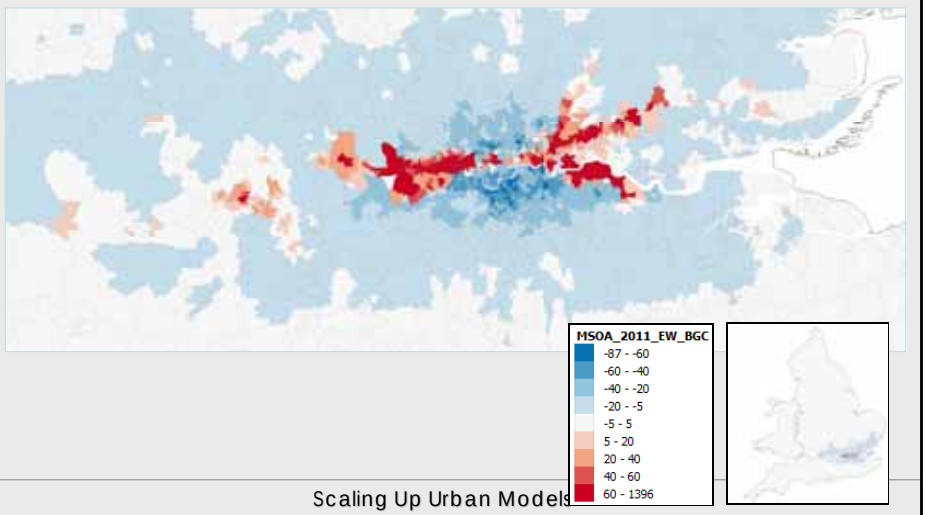
Crossrail

Population change (rail mode only)



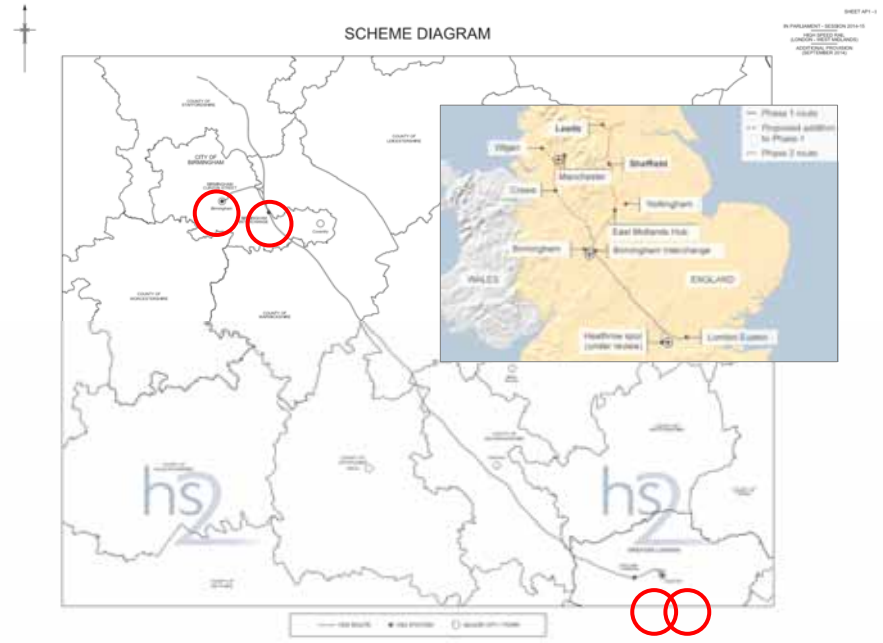
Crossrail

Population Change (all modes)



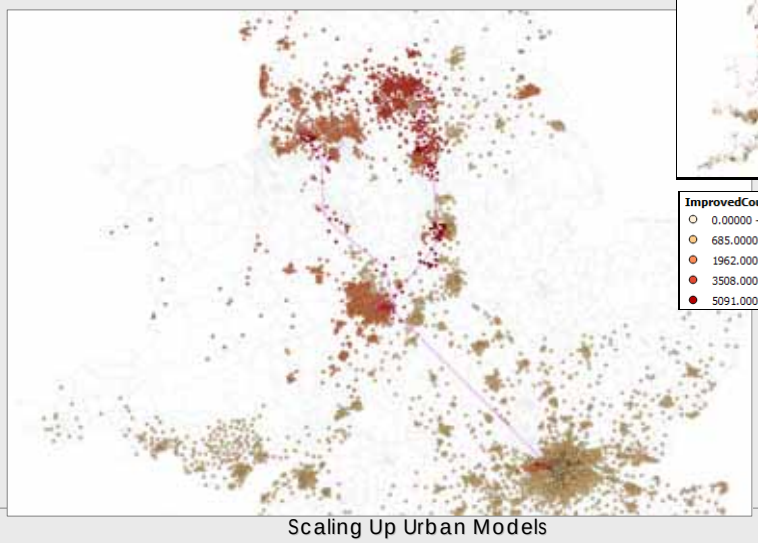
High Speed Rail



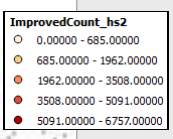


High Speed 2

Number of improved trips (ni>685)

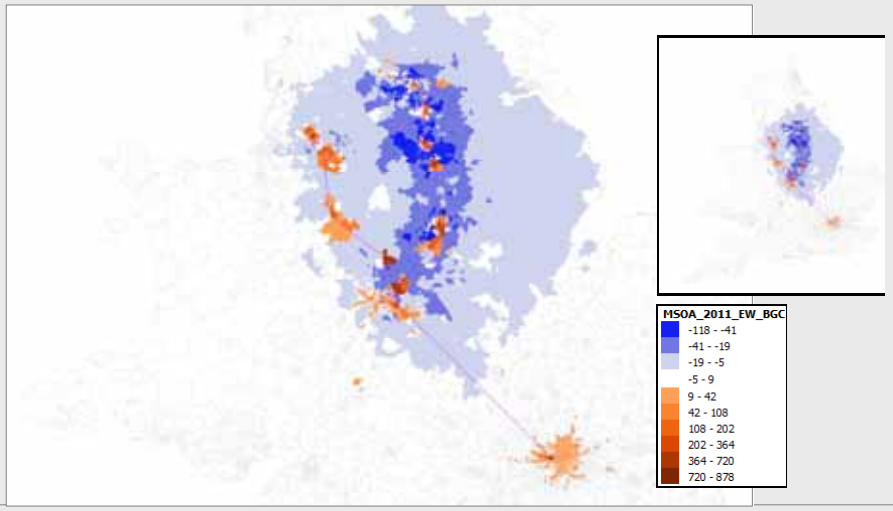


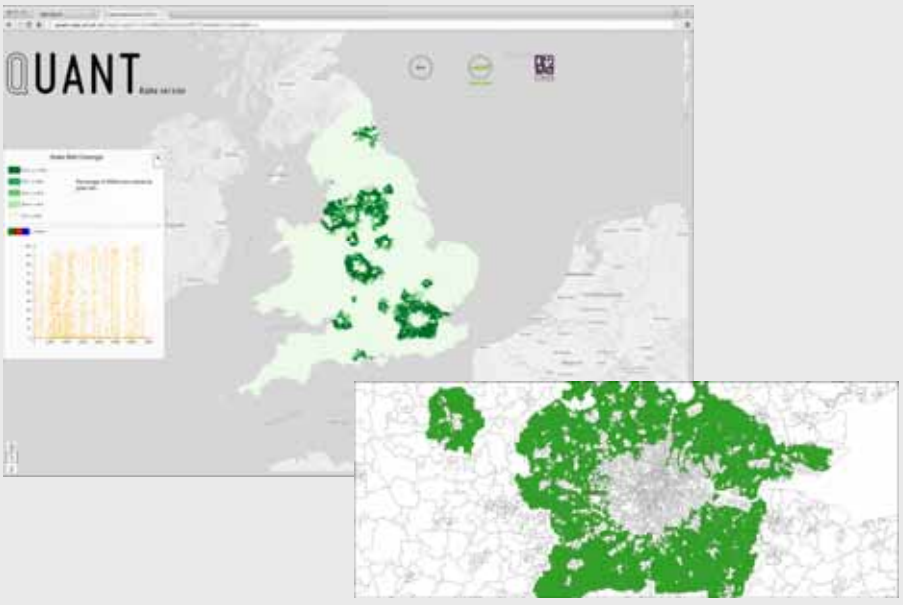


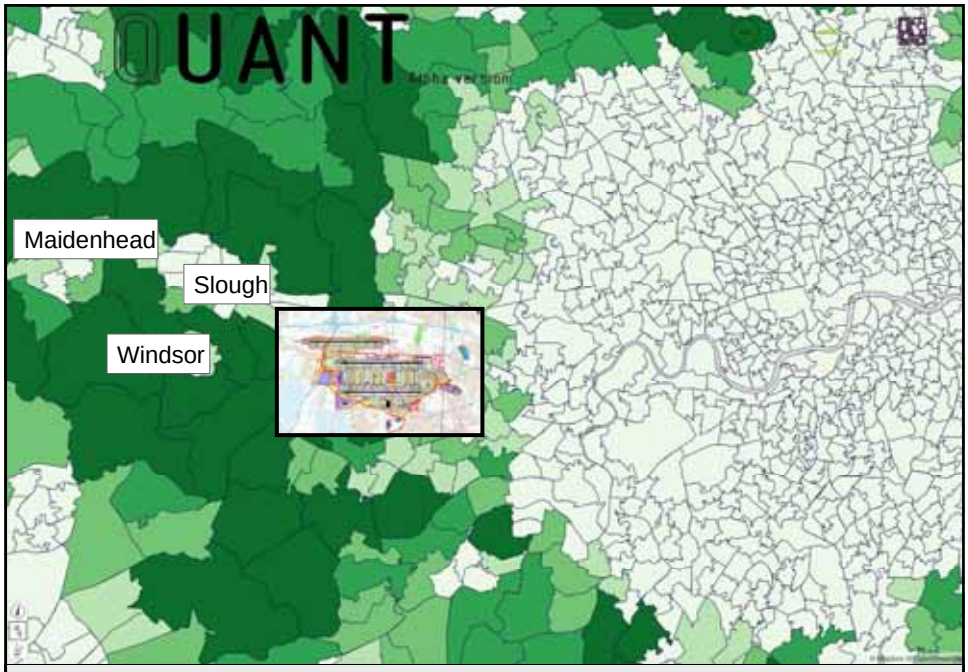


High Speed 2

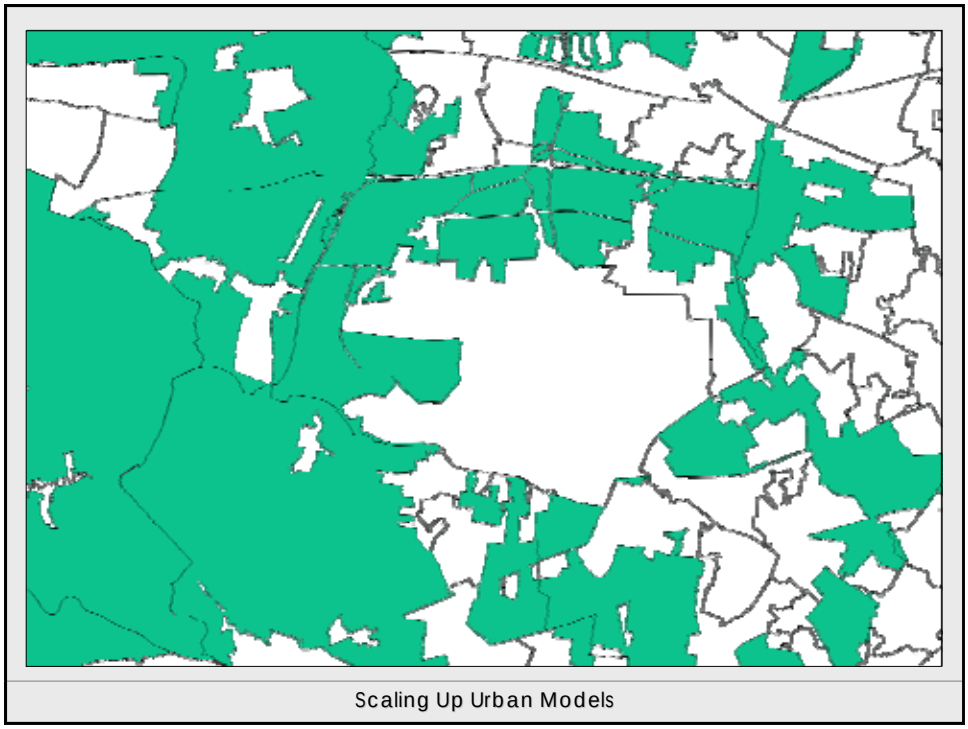
Population change (all modes)



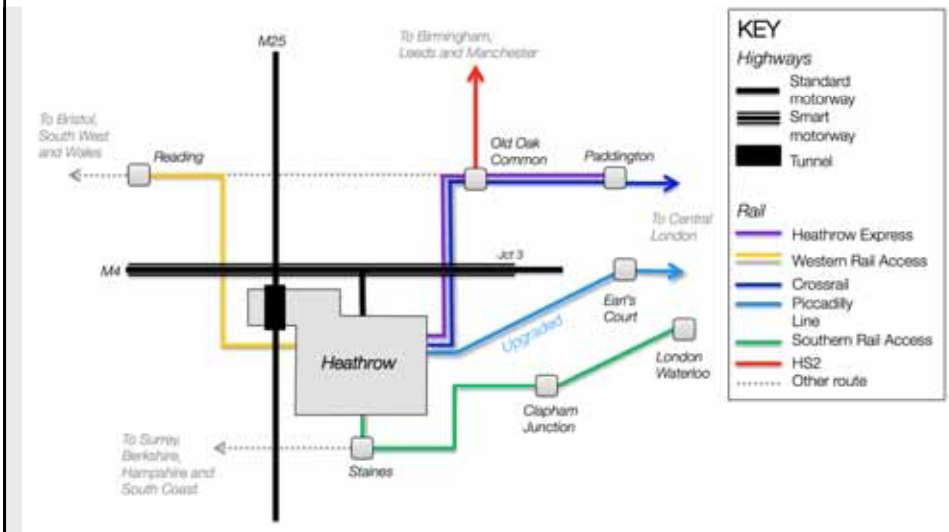




Scaling Up Urban Models

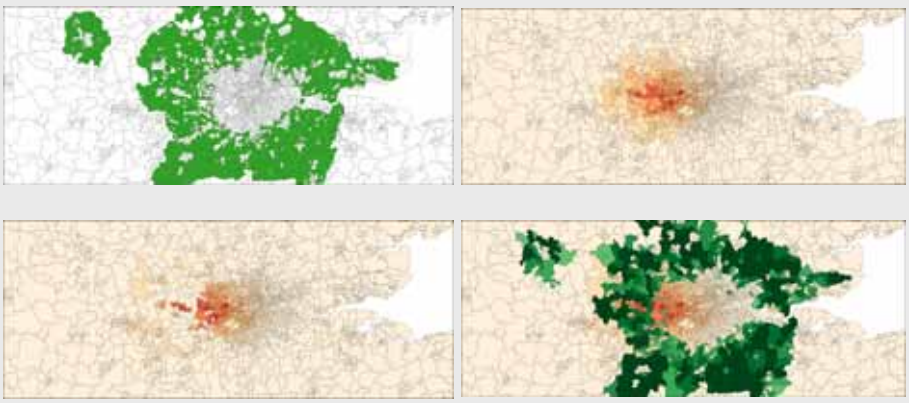


Scaling Up Urban Models



Scaling Up Urban Models

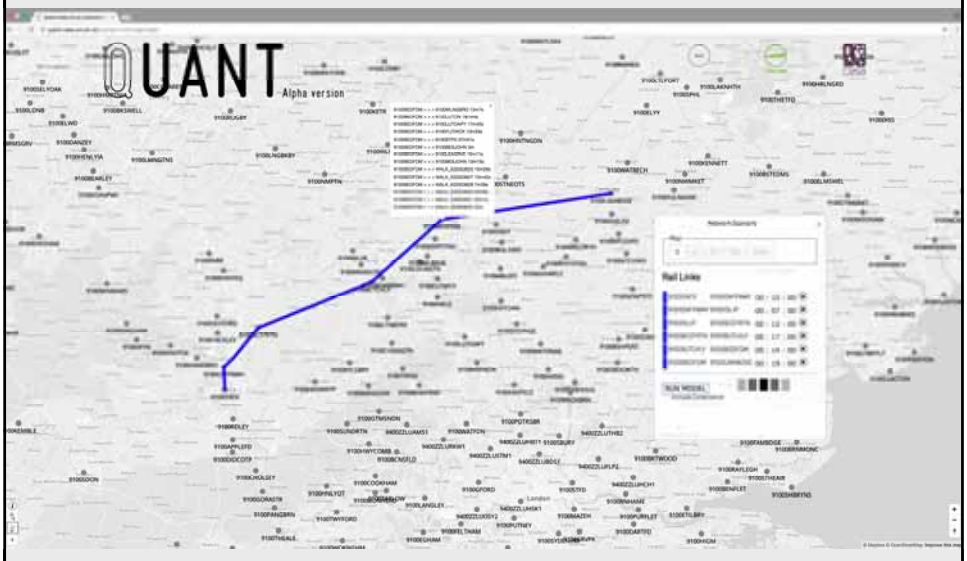
We have Tested the Impact of the Fourth Runway on E&W in terms of Where the Population from an Extra 5000 Jobs will Locate



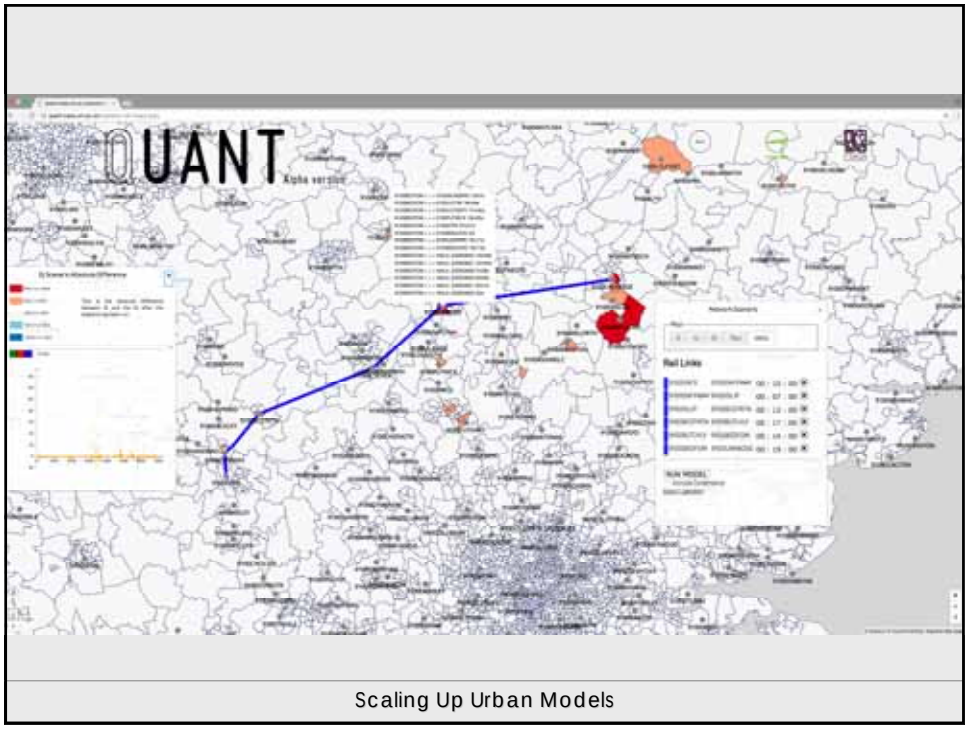
Scaling Up Urban Models



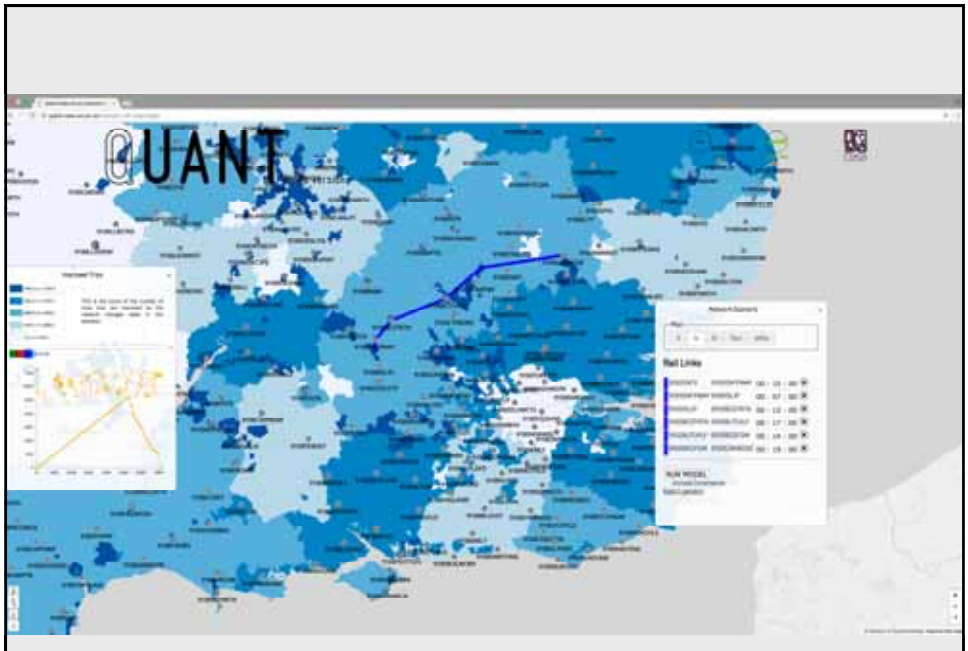
Scaling Up Urban Models



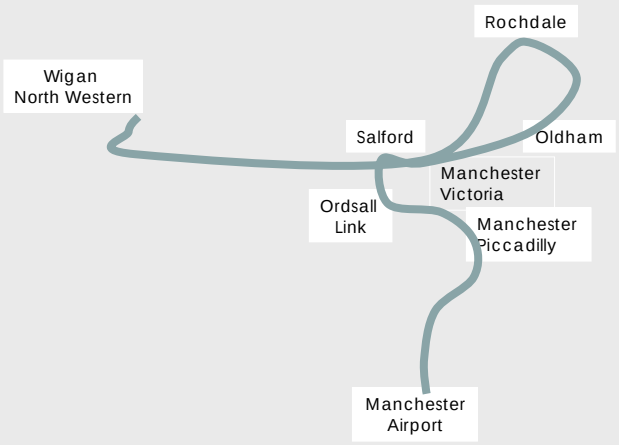
Scaling Up Urban Models



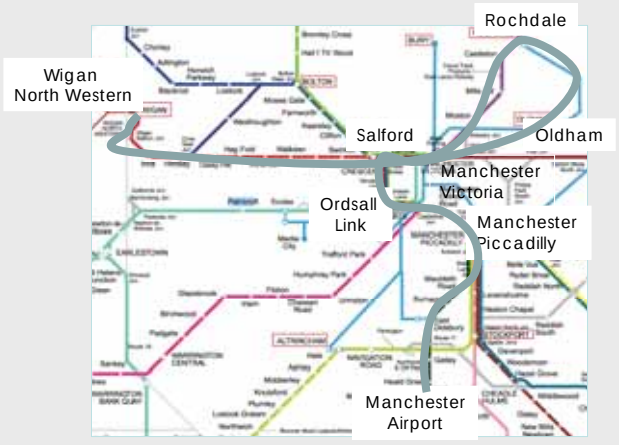
Scaling Up Urban Models



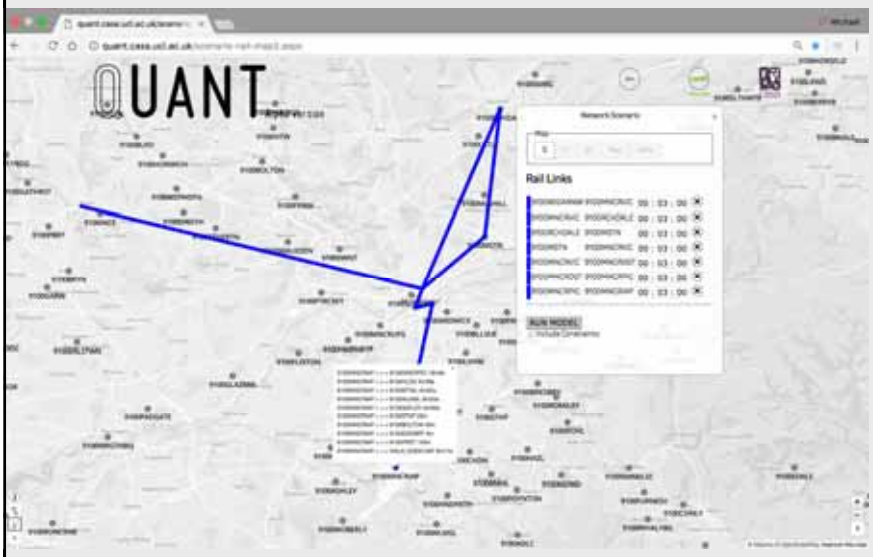
Scaling Up Urban Models



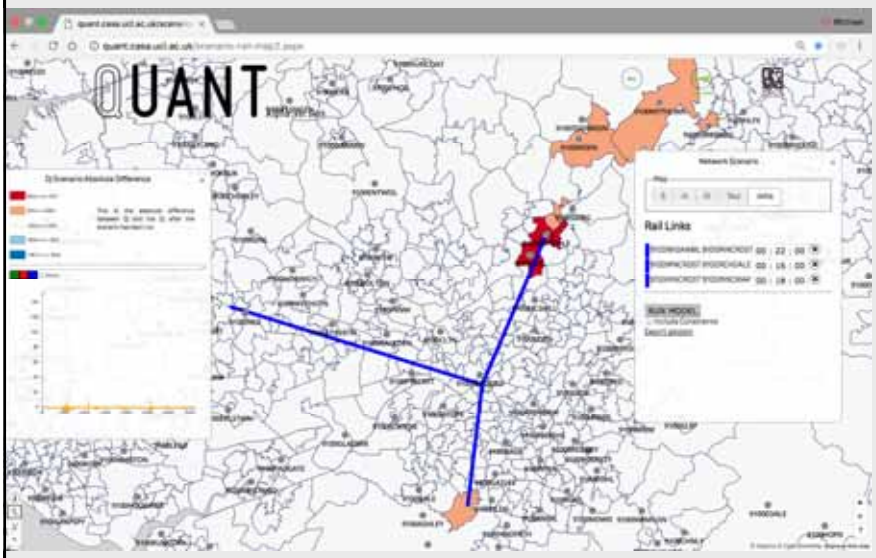
Scaling Up Urban Models



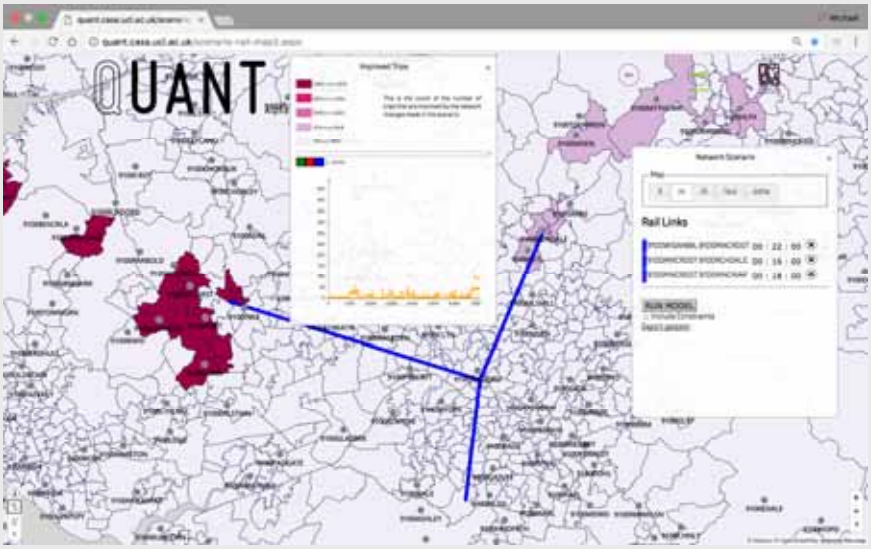
Scaling Up Urban Models



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CATAPULT Future Cities

UKCRIC
UK Collaboratorium for Research in Infrastructure & Cities

Infrastructure and Projects Authority

National Infrastructure Commission

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QUANT

stands for

Quantitative **U**rban **AN**alytics forec as**T**ing

or some variant thereof

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