

Urban Simulation 4

a. Spatial Interaction Models, and General Urban Models

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Outline of Today's Lecture

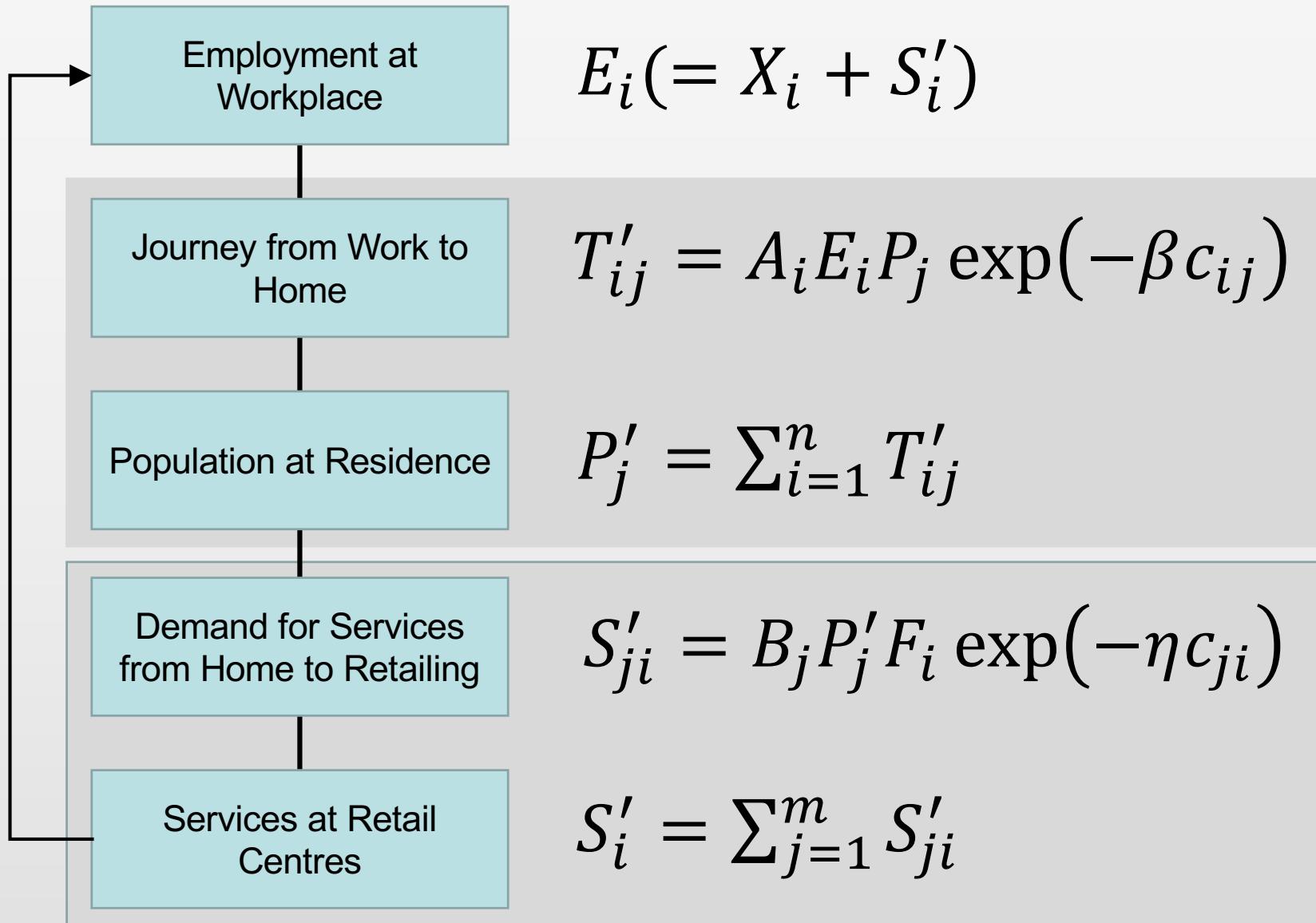
- Urban Models: Coupled Spatial Interaction
- The Economic Base Structure Again
- Generalising the Urban Model: Applications
- The UK Digital Twin: The QUANT Model
- Development Models: Cellular Automata
- Space Filling and Fractal Systems
- Early One Dimensional Automata – our first programming interlude
- Game of Life: John Conway's Contribution
- Applications through Cellular Automata etc.

Urban Models: Coupled Spatial Interaction

Ok – we have the building blocks of more comprehensive urban models now. Imagine we want to build a model of where people work, where they live and where they shop.

We first define where people work as employment at origins E_i and where they live as population at destinations P_j . This can be modelled as a singly constrained model where we predict P_j from E_i and then we predict where these people P_j will shop which relates to the number of workers or size of the shopping centre S_i at the origins.

We thus start with journey to work model defined as



I am going to add a third sector – other employment to our model – sometimes it is called ‘basic employment’ and we can model this using a potential function. So we have two kinds of employment –

The Economic Base Structure Again

I am going to add a third sector – other employment to our model – sometimes it is called ‘basic employment’ and we are going to model this using a potential function. So we have two kinds of employment –

- manufacturing & public X_i - Basic employment
- retail and commerce S_i

where $E_i = X_i + S_i$ and we have of course population P_j .

Now let us first restate the identity that total employment is equal to basic and non basic as

$$E = X + S$$

And then we scale total employment to population using an activity rate α to get

$$P = \alpha E = \alpha(X + S)$$

Note that $\alpha = P/E$

Now service or non-basic employment is a function of population – it depends on population and this ratio is called the population serving ratio defined as β

Now we can generate this services or non-basic from

$$S = \beta P = \beta \alpha(X + S)$$

Multiplying this out we get

$$S = \beta\alpha X + \beta\alpha S$$

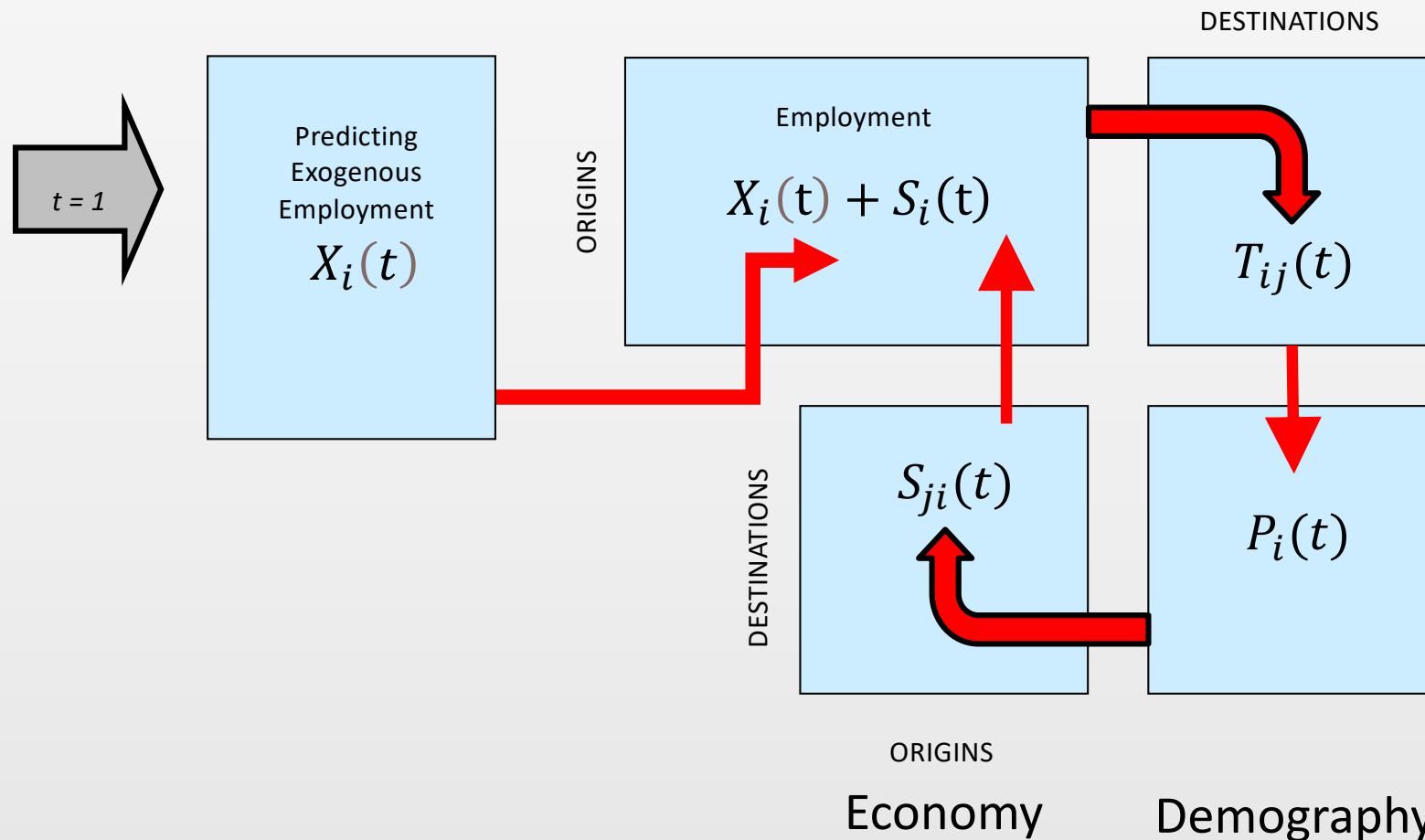
And we can then simplify this by bringing terms to the LHS of the equation as

$$\left. \begin{aligned} S(1 - \beta\alpha) &= S - \beta\alpha S = \beta\alpha X, \quad \text{and} \\ S &= \beta\alpha X(1 - \beta\alpha)^{-1} \end{aligned} \right\}$$

So given basic we can get non-basic and these are related by the multiplier

$$(1 - \beta\alpha)^{-1}$$

Now we can draw a block diagram of this so we can see how we can generate it in the following sequence of operations – or ‘workflow’ if you like.

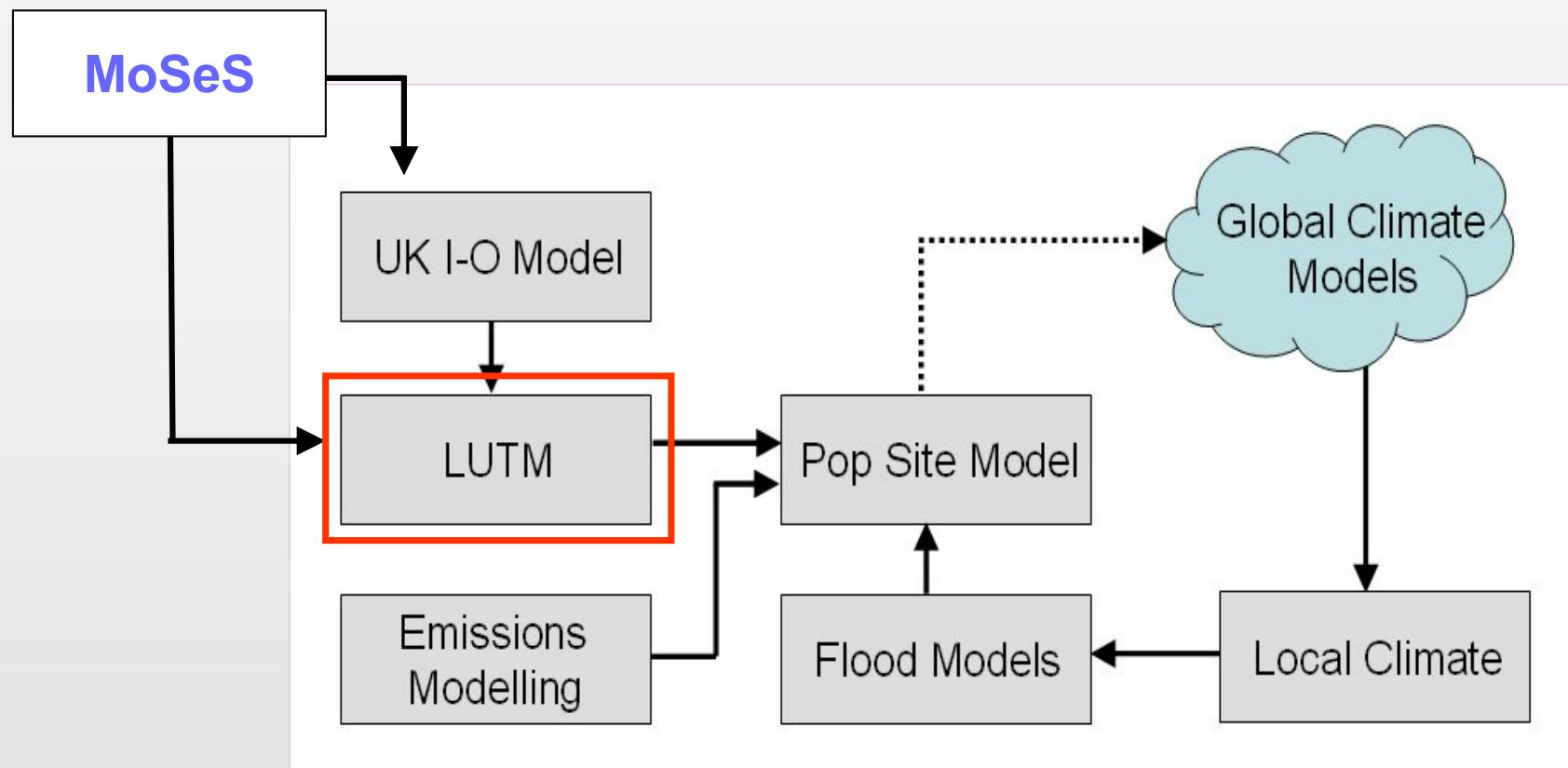


We can keep on extending the model in this way with different sectors

Generalising the Urban Model: Applications

1. A simple gravitational model for Greater London – linked to other models focussed on integrating different infrastructure and economic models
2. The extended model for Greater London and the outer metropolitan area – three sector urban model called SIMULACRA
3. A simple model built rapidly in a two days - a demo for Dubai based on data extracted from the web
4. A large scale LUTI land use transportation interaction model for the UK called QUANT – we will talk about this next time in our fourth lecture

I will not repeat the Tyndall Climate Change project
but more on to the London models, then Dubai and
eventually the Great Britain digital twin



We have strung three models together for a larger version of London. We have spatial interaction models for journey to work (Emp to Pop), for demand for employment from services (Pop to Service) and then employment based on population potential at employment location.

These models are:

$$X_i(t) = K \sum_j P_j(t) / d_{ij}$$

$$E_i(t) = X_i(t) + S_i(t)$$

$$P_j(t+1) = \sum_i A_i E_i(t) P_j(t) \exp(-\beta c_{ij})$$

$$S_i(t+1) = \sum_j B_j P_j(t+1) S_i(t) \exp(-\gamma c_{ij})$$

This is the order in which the operations take place

Sequence
of Model
Functions

Activity
Totals

Map
Graphics

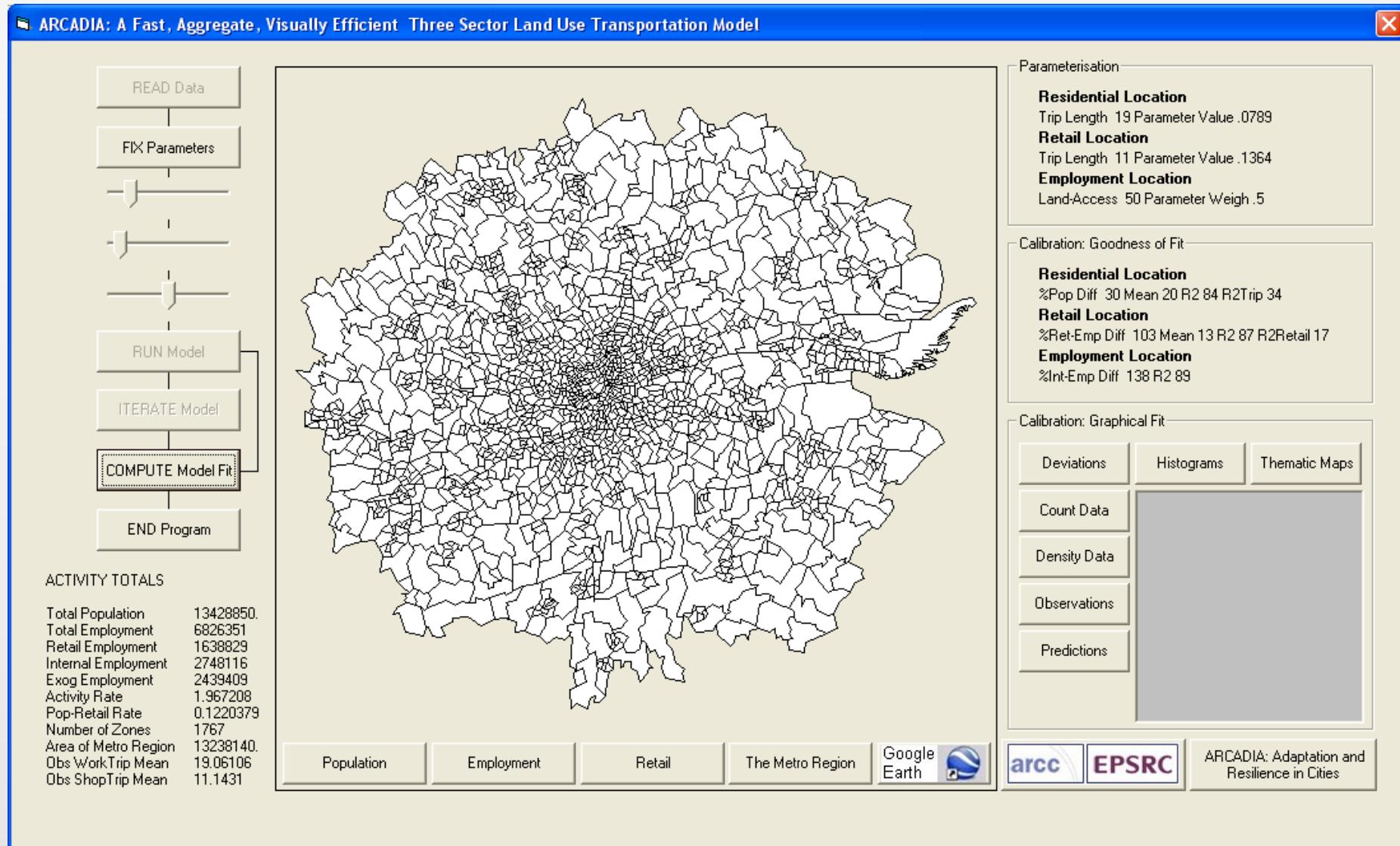
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Values

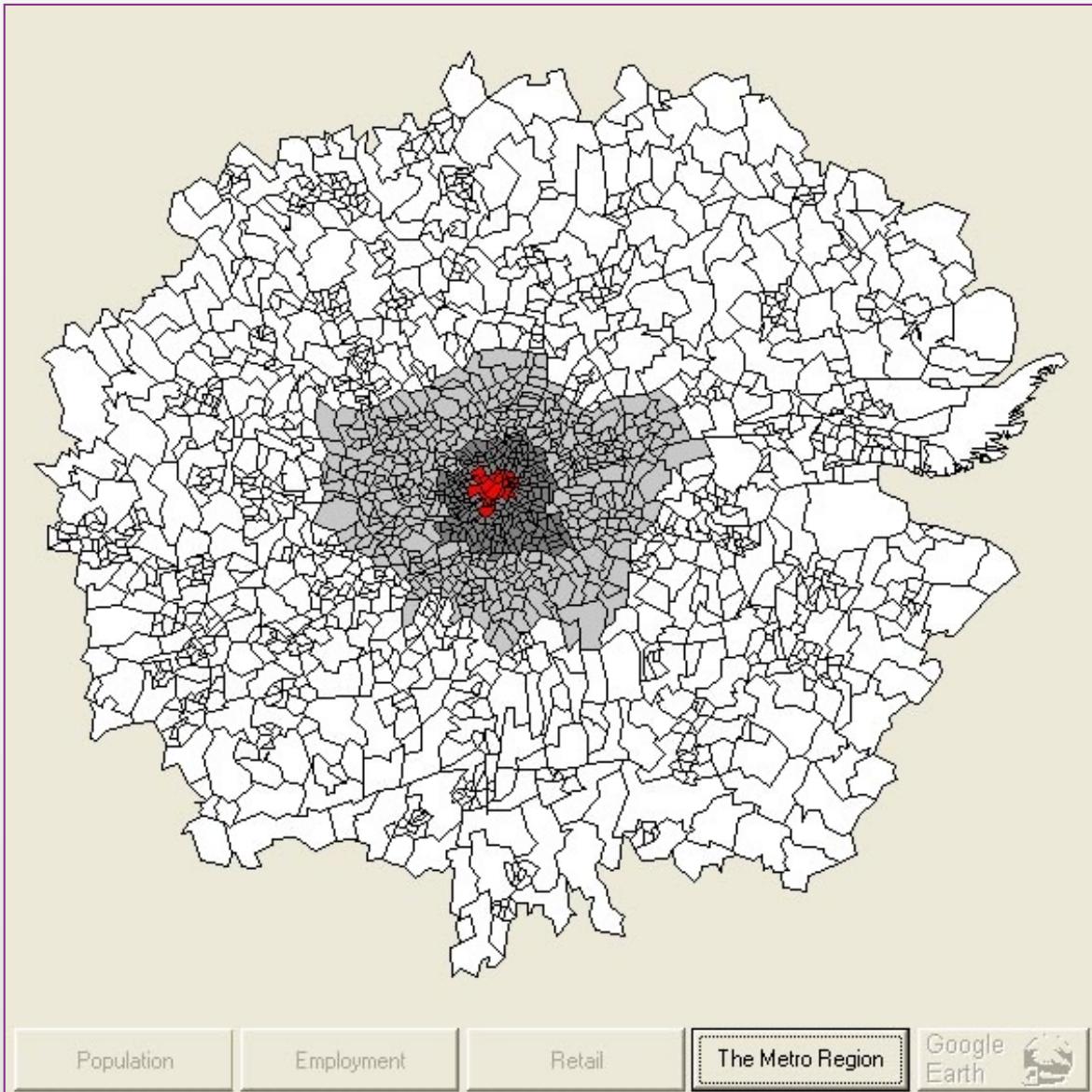
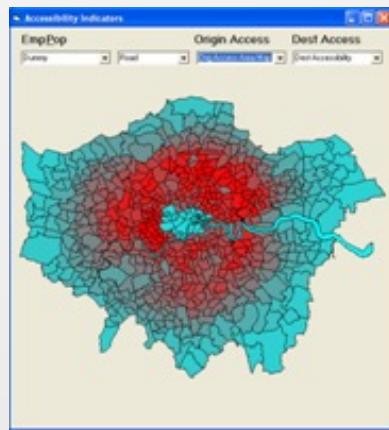
Goodness of Fit
Statistics: Deviations
& r²

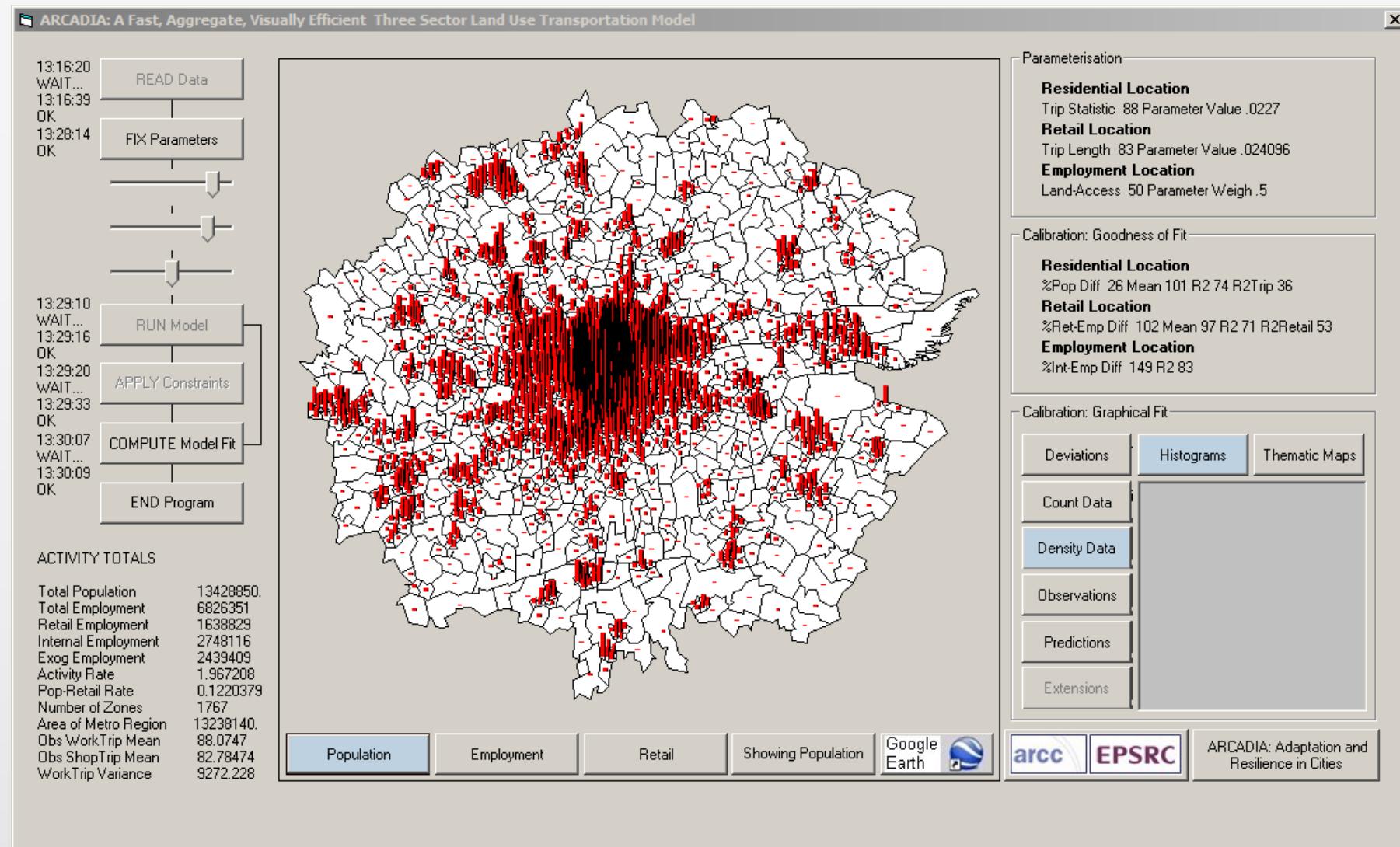
Graphical Functions

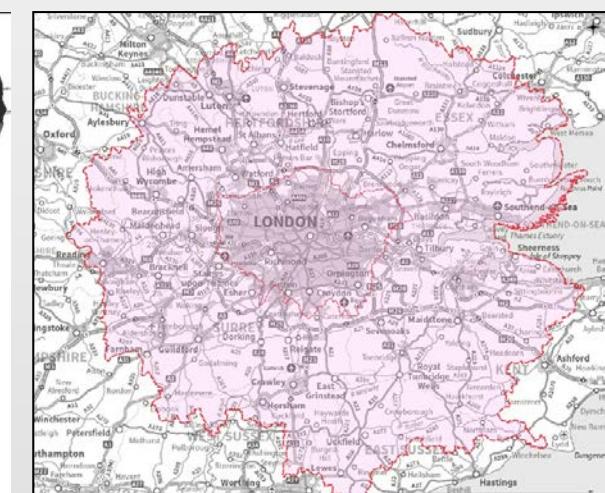
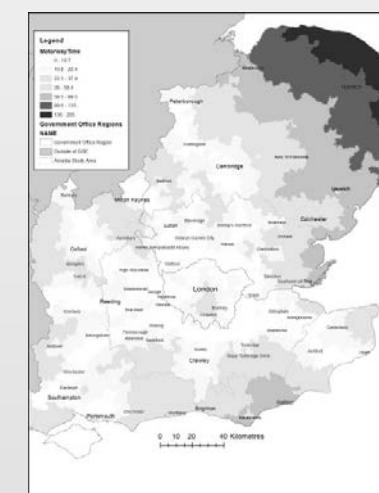
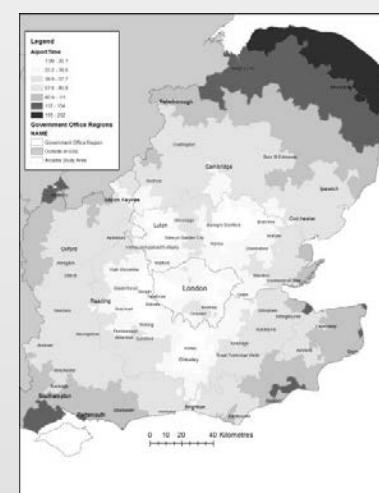
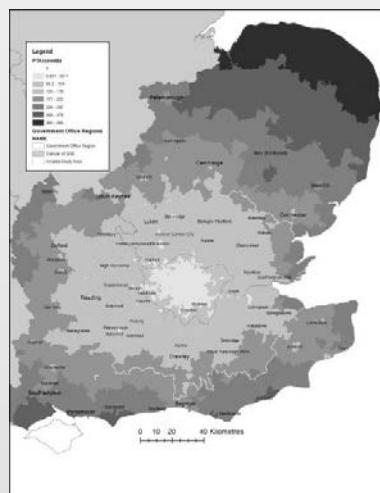
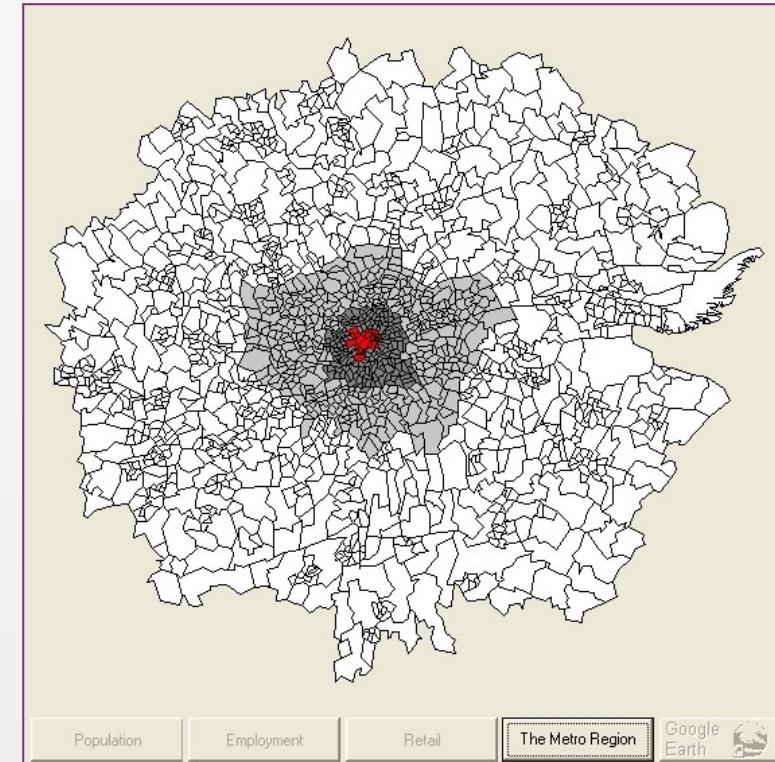
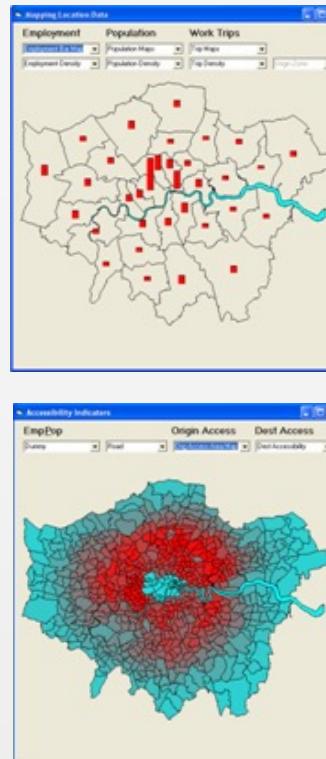
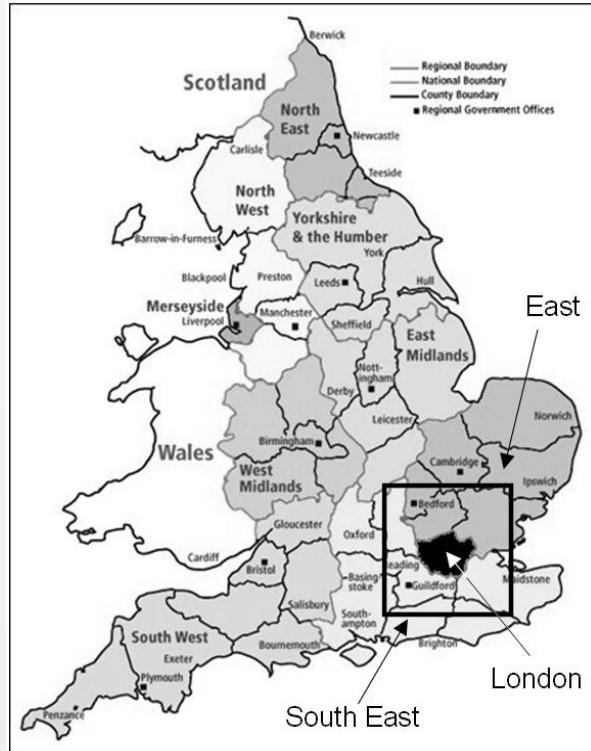
Graph
Data

Logo





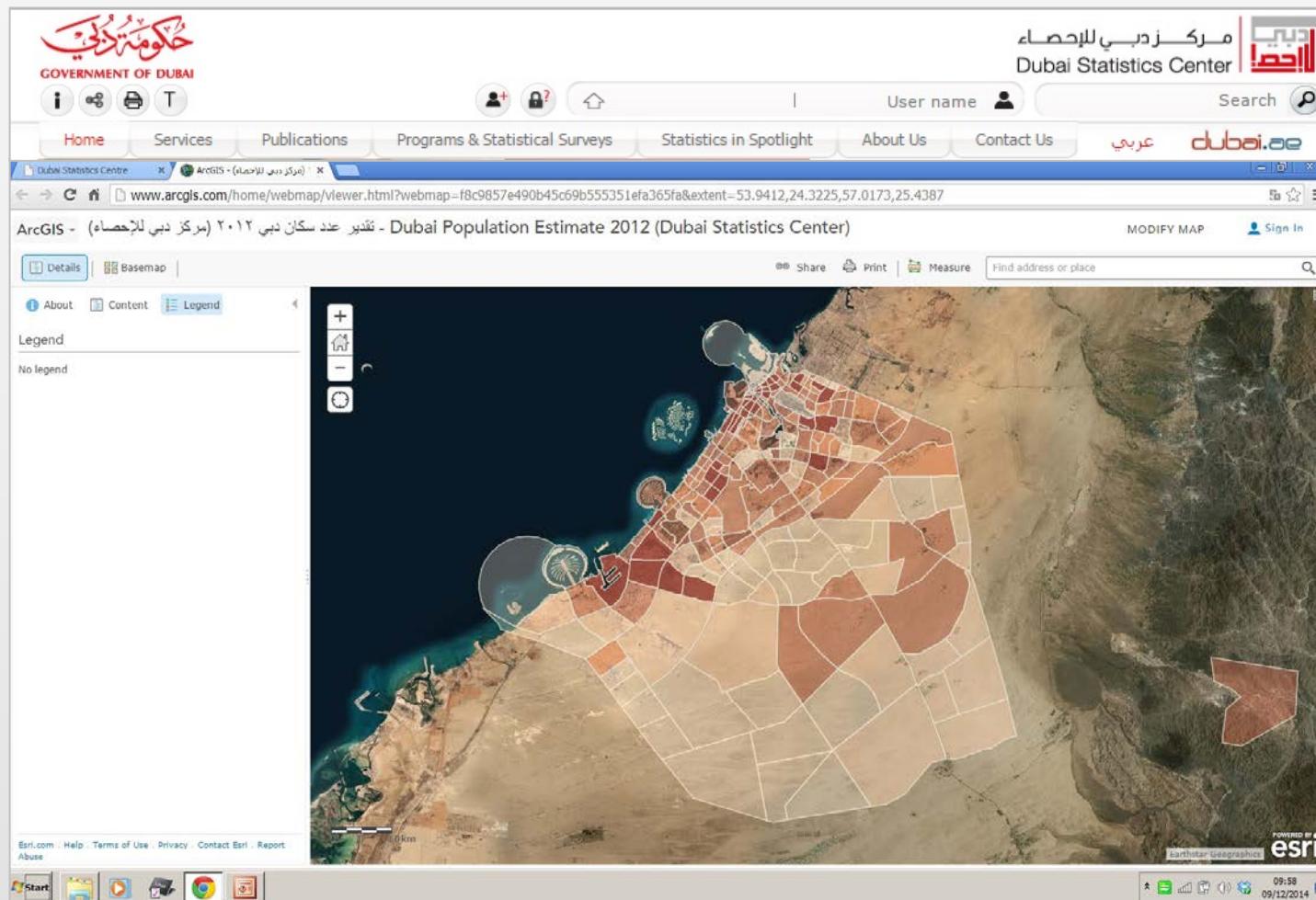




Spatial Interaction Models, and General Urban Models

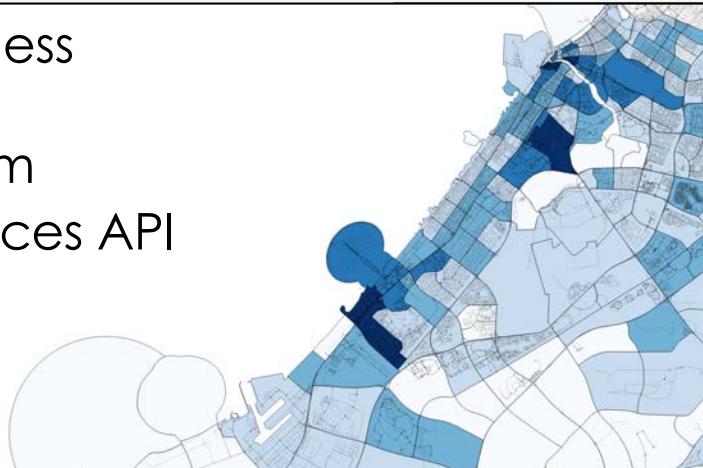
Quick and Dirty Models

A New Retail Centre in Dubai

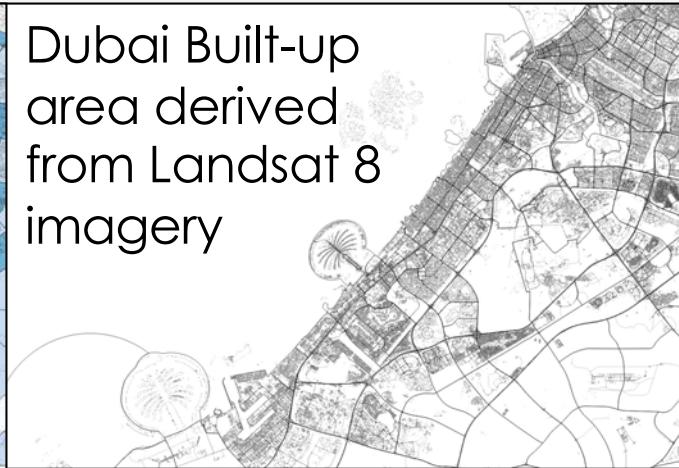


Where did we get the data – in a data poor environment?

Dubai Business Density derived from Google Places API



Dubai Built-up area derived from Landsat 8 imagery



Dubai Business Diversity Density Index





Computer



Recycle Bin



DESKTOP



Dubai-Model

CASA and the Future Cities Catapult Projects

Predicting Urban Futures for Dubai

Simulating Land Use, Population, Employment, Retailing, and Transportation

Dubai Population Estimate 2012 (Dubai Statistics Center)
تقدير عدد سكان دبي ٢٠١٢ - (مركز دبي للإحصاء)

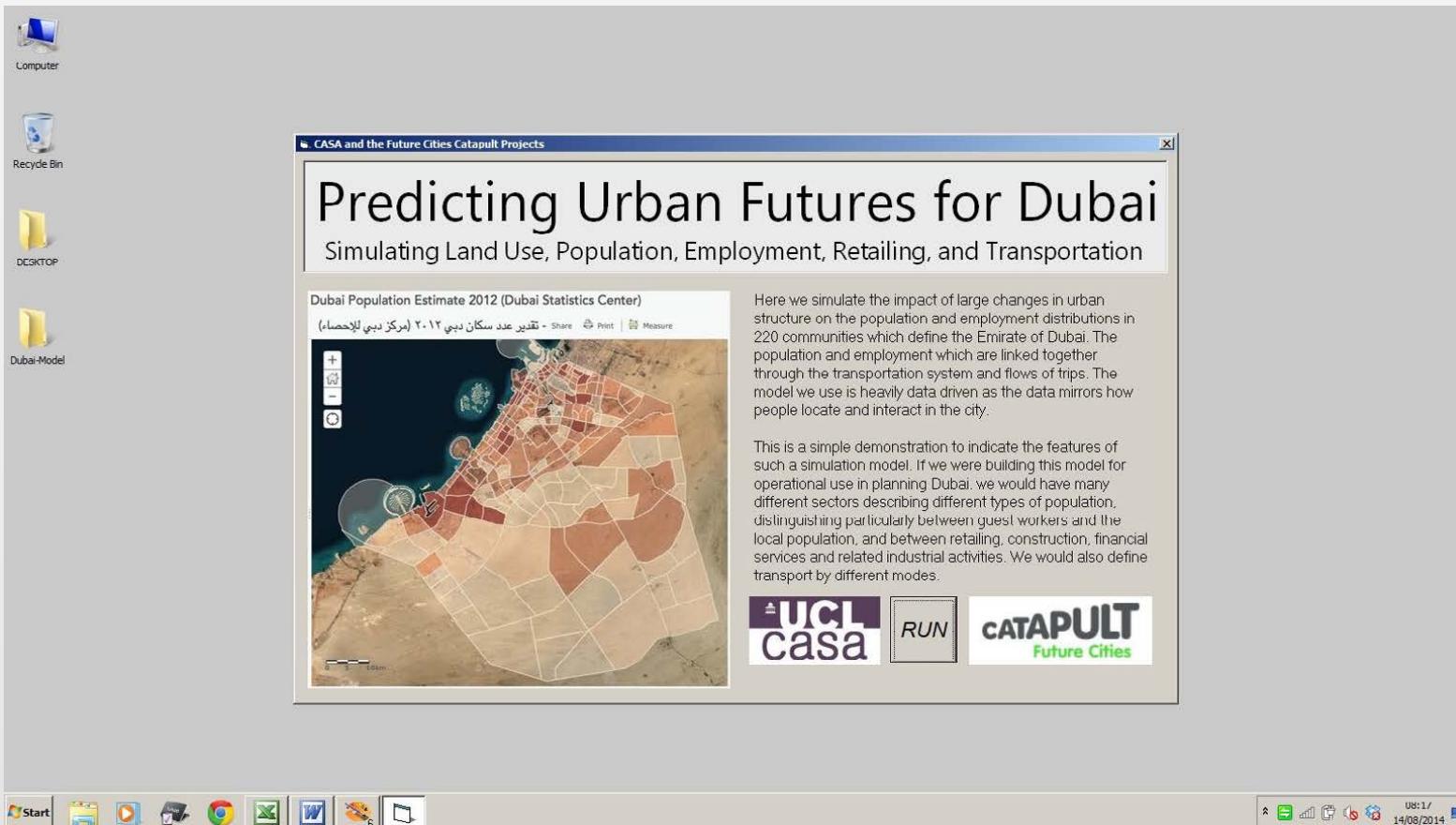
Here we simulate the impact of large changes in urban structure on the population and employment distributions in 220 communities which define the Emirate of Dubai. The population and employment which are linked together through the transportation system and flows of trips. The model we use is heavily data driven as the data mirrors how people locate and interact in the city.

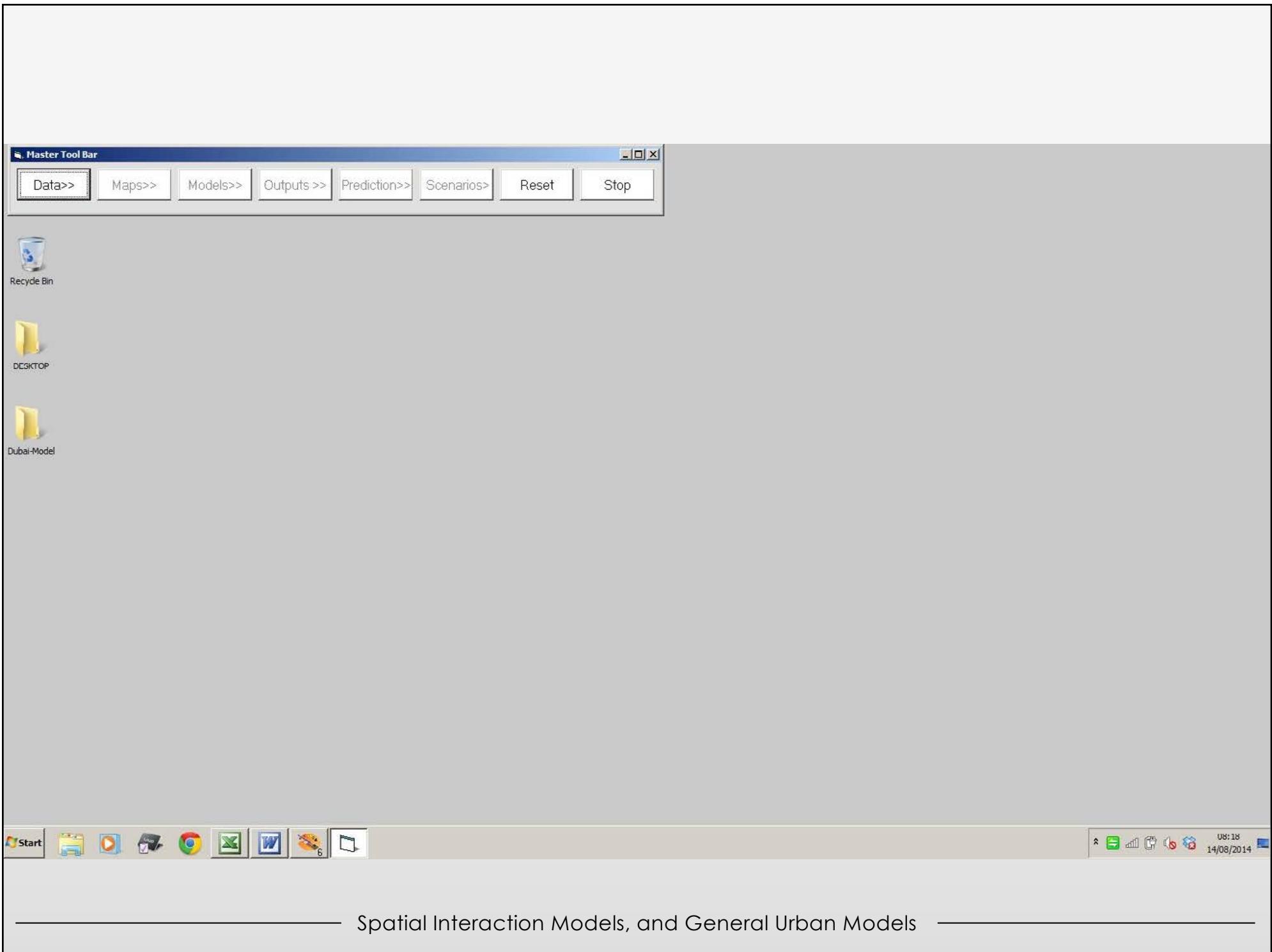
This is a simple demonstration to indicate the features of such a simulation model. If we were building this model for operational use in planning Dubai, we would have many different sectors describing different types of population, distinguishing particularly between guest workers and the local population, and between retailing, construction, financial services and related industrial activities. We would also define transport by different modes.

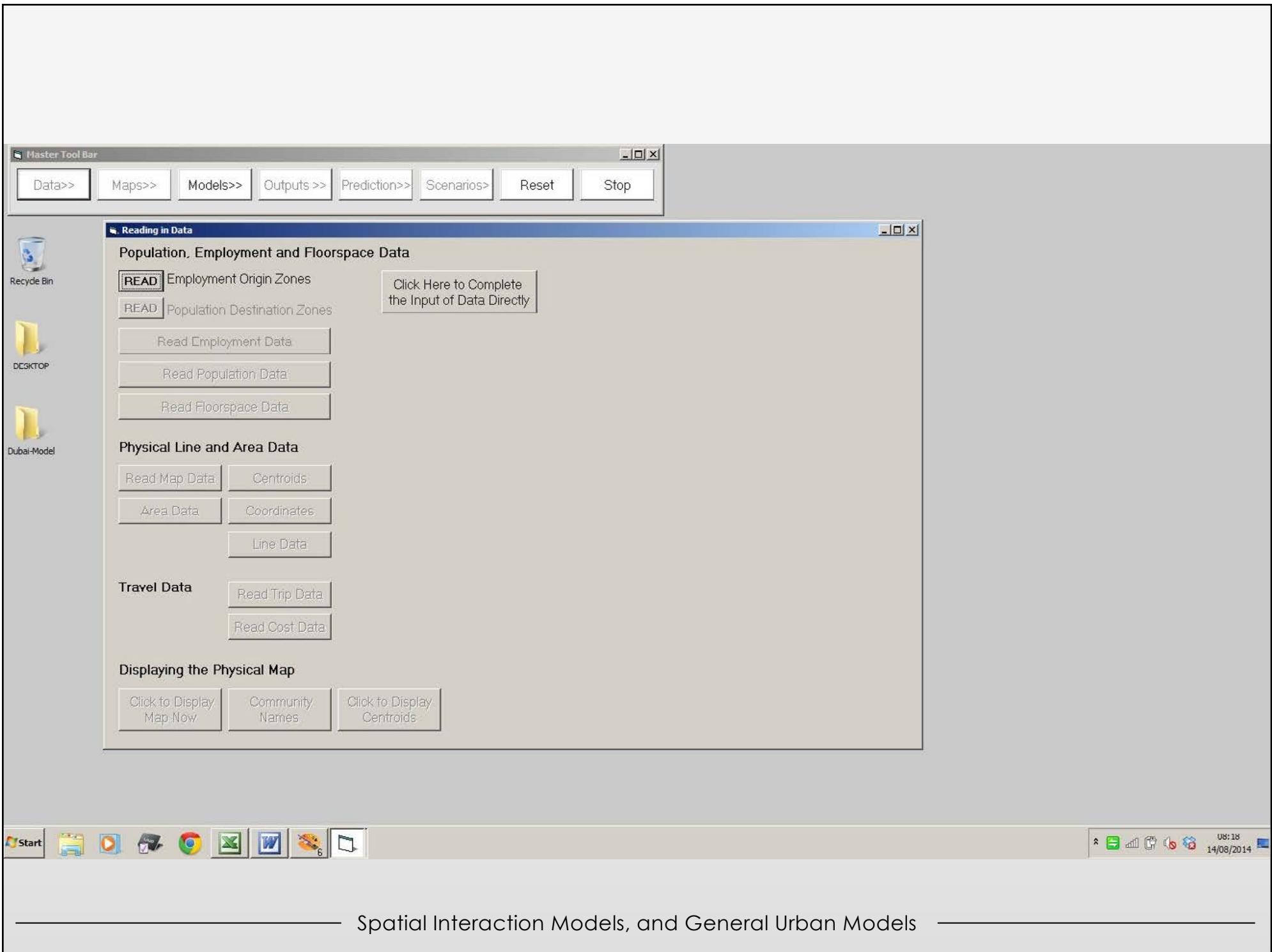
UCL casa **RUN** **CATAPULT**
Future Cities

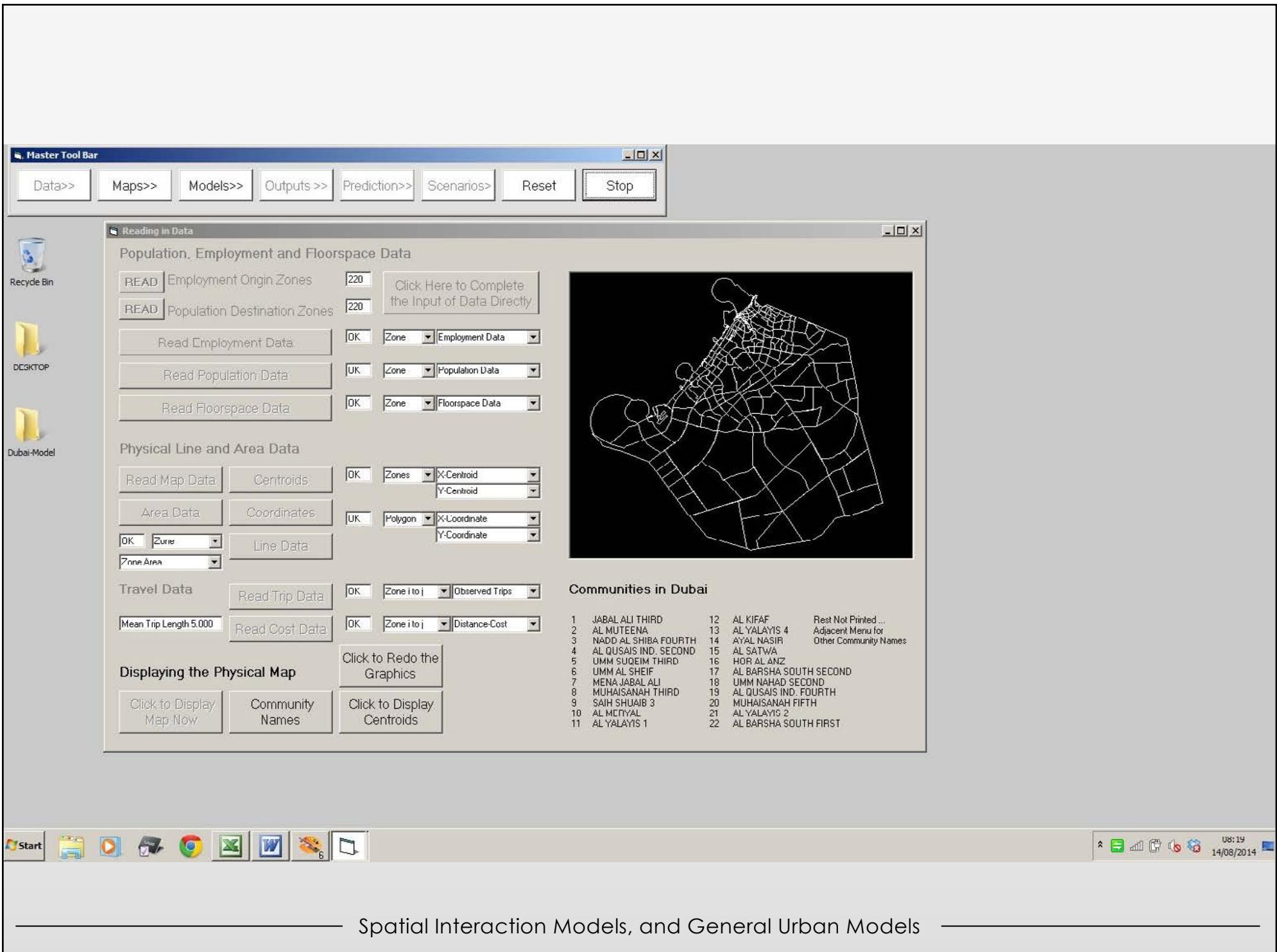


I can show you a quick movie that we demoed to the guys from Dubai who came to see us about 8 years ago









Master Tool Bar

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Data

Reading in Data

Population, Employment and Floorspace Data

READ Employment Origin Zones [220] Click Here to Complete the Input of Data Directly

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Read Employment Data OK Zone Employment Data

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Physical Line and Area Data

Read Map Data Centroids OK Zones X-Centroid Y-Centroid

Area Data Coordinates UK Polygon X-Coordinate Y-Coordinate

OK Zone Line Data Zone Area

Travel Data Read Trip Data OK Zone i to j Observed Trips

Mean Trip Length 5.000 Read Cost Data OK Zone i to j Distance-Cost

Displaying the Physical Map

Click to Display Map Now Community Names Click to Redo the Graphics Click Here If You Wish to Close This Interface

Communities in Dubai

1 JABAL ALI THIRD	12 AL KIFAF	Rest Not Printed ...
2 AL MUTEENA	13 AL YALAYIS 4	Adjacent Menu for
3 NADD AL SHIBA FOURTH	14 ATAYL NASIR	Other Community Names
4 AL QUSAIS IND. SECOND	15 AL SATWA	
5 UMM SUQEIM THIRD	16 HOR AL ANZ	
6 UMM AL SHEIF	17 AL BARSHA SOUTH SECOND	
7 MENA JABAL ALI	18 UMM NAHAD SECOND	
8 MUHAISANAH THIRD	19 AL QUSAIS IND. FOURTH	
9 SAIH SHUAIB 3	20 MUHAISANAH FIFTH	
10 AL MCNYAL	21 AL YALAYIS 2	
11 AL YALAYIS 1	22 AL BARSHA SOUTH FIRST	

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Spatial Interaction Models, and General Urban Models

Master Tool Bar

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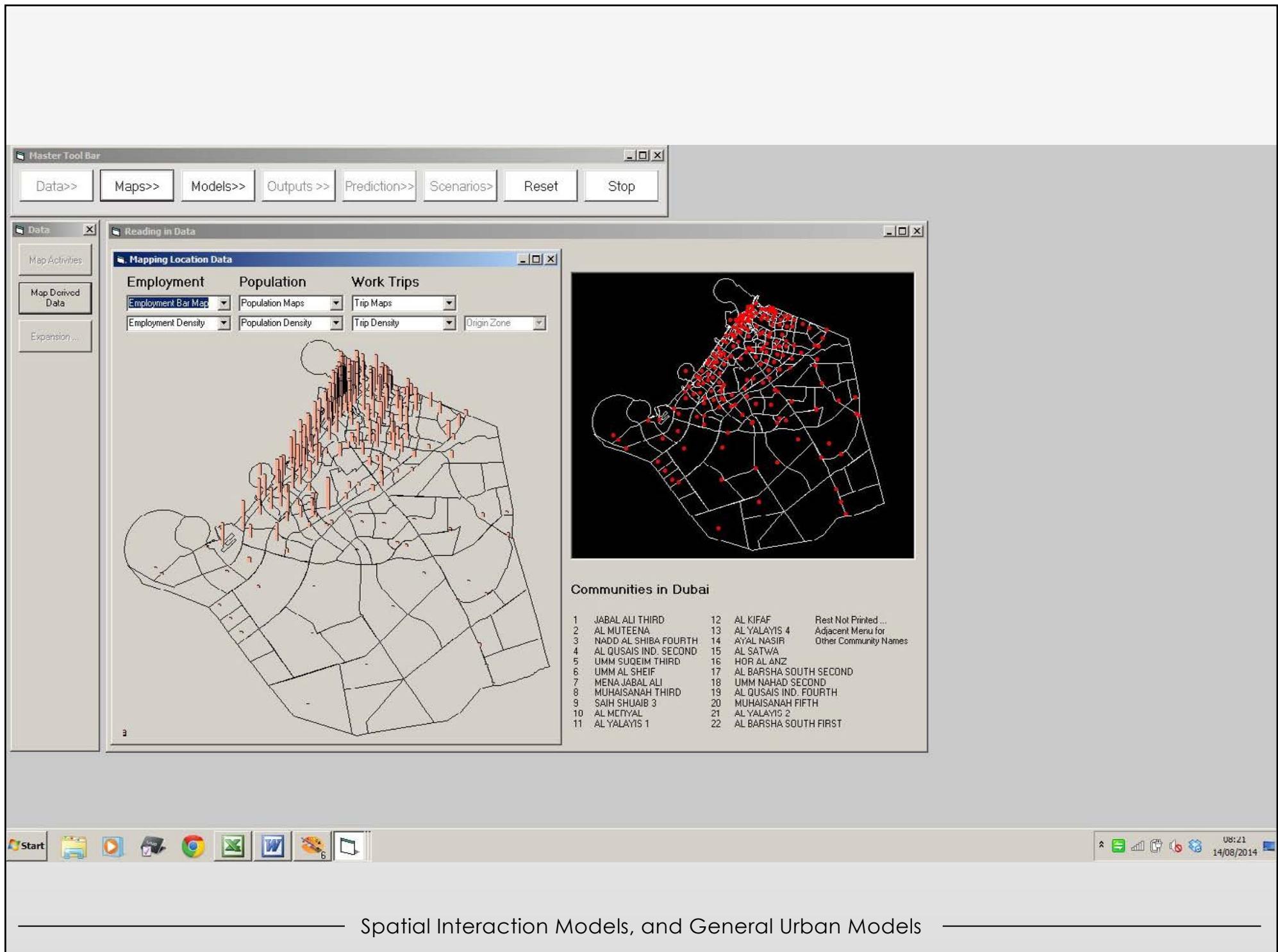
List of Community Names

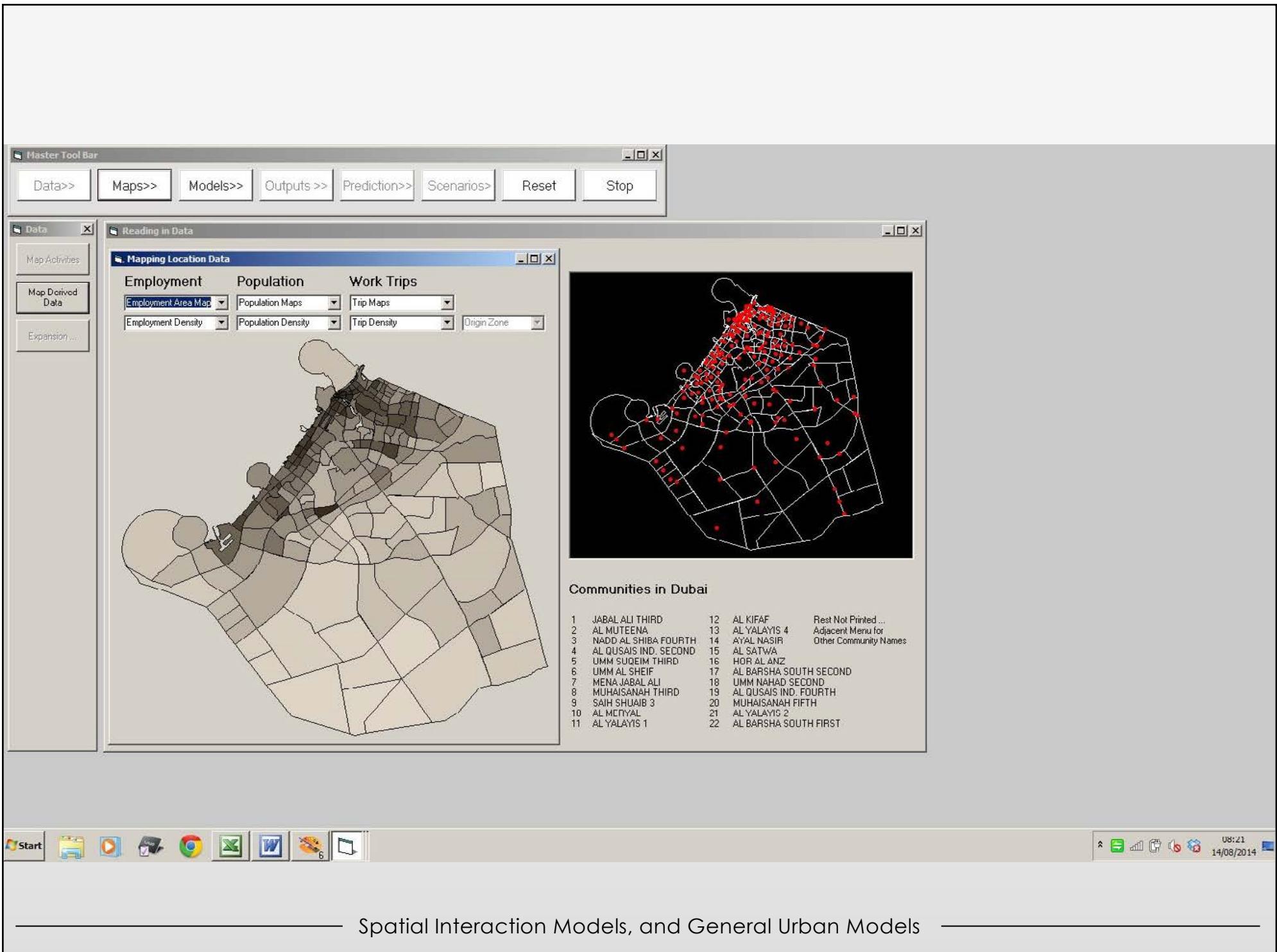
Community Name	Community Name	Community Name	Community Name	Community Name	Community Name
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2 AL MUTECCA	47 UMM NAIAD FIRST	92 AL WANDA/QA' FOUNTI	137 AL DANCIA COUTI THIIND	102 AL TWAR THIIND	
3 NADD AL SHIBA FOURTH	48 HEFAIR	93 RAS AL KHOR IND. FIRST	138 AL KHEERAN FIRST	183 AL GARHOUD	
4 AL QUSAIS IND. SECOND	49 WARSAN THIRD	94 MARGHAM	139 NAKHLAT DEIRA	184 AL JAFLIYA	
5 UMM SUQEIM THIRD	50 MUHAISNAH SECOND	95 AL TTAY	140 AL RAS	185 NAZWAH	
6 UMM AL SHEIF	51 AL QUSAIS THIRD	96 AL BARAHA	141 WADI AL SAFA 5	186 AL LAYAN 2	
7 MENA JABAL ALI	52 AL MURAQQABAT	97 AL YALAYIS 5	142 AL QOUZE IND.FOURTH	187 MANKHOOL	
8 MUHAISNAH THIRD	53 NAIF	98 PORT SAED	143 UMM SUEIM SECOND	188 NADD HESSA	
9 SAIH SHUAIB 3	54 AL QOUZ FIRST	99 AL MIZHAR FIRST	144 AL SAFA SECOND	189 MUHAISNAH FOURTH	
10 AL MERYAL	55 MARGAB	100 AL QOUZE IND.THIRD	145 NADD SHAMMA	190 AL BARSHA SECOND	
11 AL YALAYIS 1	56 AL HEBIAH SECOND	101 AL MAMZAR	146 SAIH SHUAJALAH	191 AL BARSHA SOUTH FOURTH	
12 AL KIFAF	57 ABU HAIL	102 AL RAFFA	147 LE HEMAIRA	192 MUHAISNAH FIRST	
13 AL YALAYIS 4	58 JUMEIRA THIRD	103 MEREYEE	148 BU KADRA	193 AL TWAR SECOND	
14 AYAL NASIR	59 MUGATRAH	104 JUMEIRA FIRST	149 AL RIWAAJAH SECOND	194 AL HEBIAH THIRD	
15 AL SATWA	60 AL THANAYAH FOURTH	105 CORNICHE DEIRA	150 AL THANAYAH SECOND	195 UMM HURAIR FIRST	
16 HNR AI ANZ	61 NADD AI SHIRA FIRST	106 AI MIZHAR SCIND	151 AI SARKHA	196 WADI AI SAFA 4	
17 AL BARSHA SOUTH SECOND	62 AL BUTEEN	107 WADI AL SAFA 3	152 WADI AL SAFA 2	197 ALSAFOUSH SECOND	
18 UMM NAHAD SECOND	63 AL HEBIAH FIFTH	108 WADI AL SAFA 6	153 HOR ALANZ EAST	198 AL QOUZE IND.SECOND	
19 AL QUSAIS IND. FUHIIH	64 AL FAJAA'	109 AL MAHMUUM	154 AL KHWAREEJ SELUND	199 AL WASL	
20 MUHAISNAH FIFTH	65 GRAYTEESAH	110 WARSAN FOURTH	155 DUBAI INVESTMENT PARK FIRST	200 AL CORNICHE	
21 AL YALAYIS 2	66 AL YALAYIS 3	111 DUBAI INT'L AIRPORT	156 AL QUSAIS SECOND	201 MIRDIF	
22 AL BARSHA SOUTH FIRST	67 REMAH	112 AL WARQAA SECOND	157 AL HEBIAH FOURTH	202 UMM SUQEIM FIRST	
23 YARAAH	68 ME'AISEM SECOND	113 TRADE CENTER FIRST	158 WARSAN FIRST	203 GHADEER BARASHY	
24 AL LESAILY	69 SAIH AL DAHAL	114 AL AWIR SECOND	159 AL QUSAIS FIRST	204 MADINAT DUBAI AL MELAHEYAH	
25 AL NAHDA SECOND	70 JABAL ALI INDUSTRIAL FIRST	115 AL RASHIDYA	160 SAIH AL SALAM	205 AL MERKADH	
26 LEHBAB FIRST	71 MADINAT AL MATAAR	116 RIGGAT AL BUTEEN	161 RAS AL KHOR IND. SECOND	206 AL KARAMA	
27 AL HAMRIYA	72 AL THANAYAH FIRST	117 RAS AL KHOR	162 SAIH SHUAIB 2	207 AL MAHA	
28 AL SAFA FIRST	73 AL THANAYAH FIFTH	118 AL BARSHA SOUTH FIFTH	163 UMM ESELAY	208 AL WAJIEHA AL BAHRIAH	
29 AL MANARA	74 ENKHALI	119 AL HATHMAH	164 AL WARQAA THIRD	209 SAIH SHUAIB 1	
30 UMM AL MOMENEEN	75 NADD AL HAMAR	120 AL KHABAISI	165 JABAL ALI INDUSTRIAL SECOND	210 MARSA DUBAI	
31 ALEYAS	76 AL RIWAYAH THIRD	121 AL LAYAN 1	166 AL MURAR	211 UMM RAMOOL	
32 WADI ALAMARDI	77 LEHBAB SECOND	122 AL WARQAA FIRST	167 AL KHEERAN	212 ZAABEEL FIRST	
33 AL HCDIAH FIRST	78 AL YUFDAI 2	123 AL KICERAN SECOND	168 AL DANCIA FIRST	213 HADAO SI CIKII MOHAMMED D-H	
34 AL QUSAIS IND. FIFTH	79 AL SHINDAGHA	124 AL AWIR FIRST	169 UMM NAHAD THIRD	214 AL THANAYAH THIRD	
35 TRADE CENTER SECOND	80 UMM AL DAMAN	125 HESSYAN SECOND	170 NAKHLAT JABAL ALI	215 HESSYAN FIRST	
36 NADD AL SHIBA SECOND	81 AL BARSHA THIRD	126 AL TWAR FIRST	171 AL RIWAYAH FIRST	216 AL WARQAA FIFTH	
37 BURJ KHALIFA	82 QUD AL MUTEENA SECOND	127 WARSAN SECOND	172 AL WOHOOSH	217 AL NAHDA FIRST	
38 AL QUSAIS IND. THIRD	83 AL SAFOOH FIRST	128 AL QOUZ THIRD	173 RAS AL KHOR IND. THIRD	218 JABAL ALI SECOND	
39 AL QOUZ SECOND	84 AL RIYRAH 1	129 AL QUSAIS IND. FIRST	174 ME'AISEM FIRST	219 WADI AL SAFA 7	
40 ZAA'BEEL SECOND	85 JABAL ALI FIRST	130 AL HAMRIA PORT	175 JABAL ALI INDUSTRIAL THIRD	220 AL BADA'	
41 AL JADAF	86 AL SOUQ AL KABEER	131 AL WUHEIDA	176 NADD AL SHIBA THIRD		
42 JUMEIRA SECOND	87 AL RIGGA	132 QUD AL MUTEENA FIRST	177 WADI ALSHABAK		
43 DUBAI INVESTMENT PARK SECOND	88 UMM NAHAD FOURTH	133 AL O'SHOOSH	178 AL QOUZE IND.FIRST		
44 SAIH SHUAIB 4	89 MUSHRAIF	134 QUD METHA	179 AL HUDAIBA		
45 AL KHWAREEJ FIRST	90 QUD AL MUTEENA THIRD	135 NAKHLAT JUMEIRA	180 AL DAGHAYA		

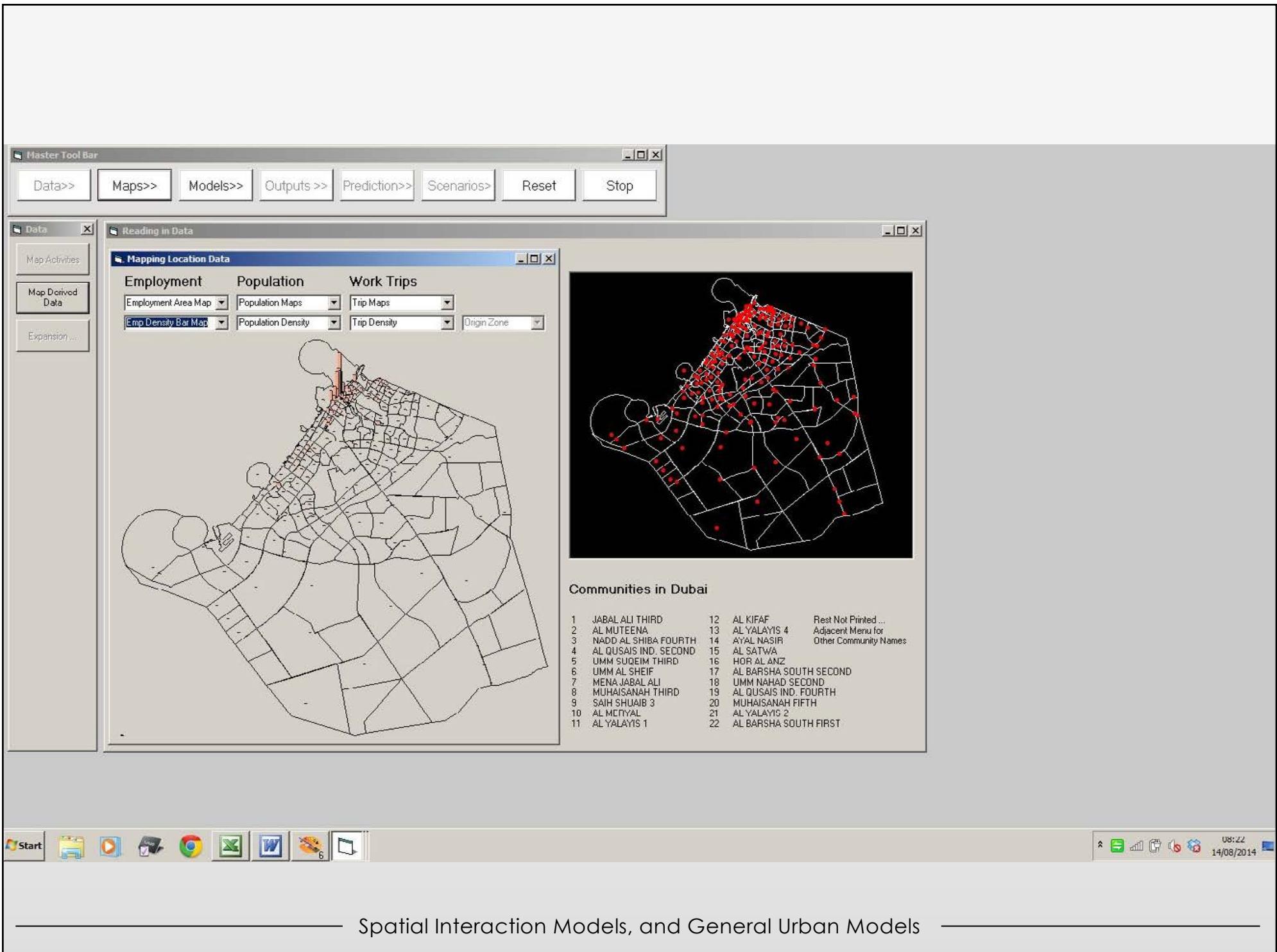
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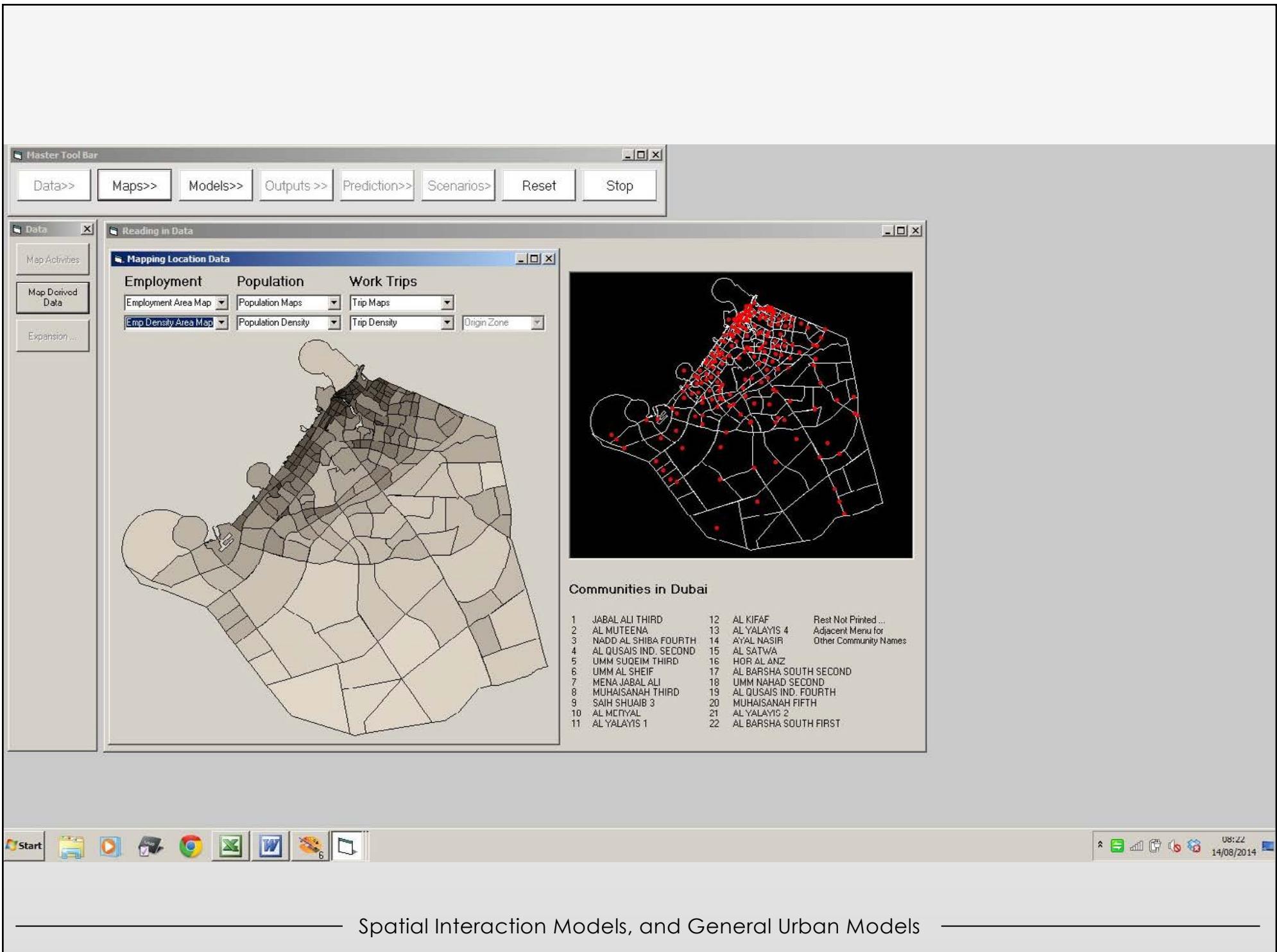
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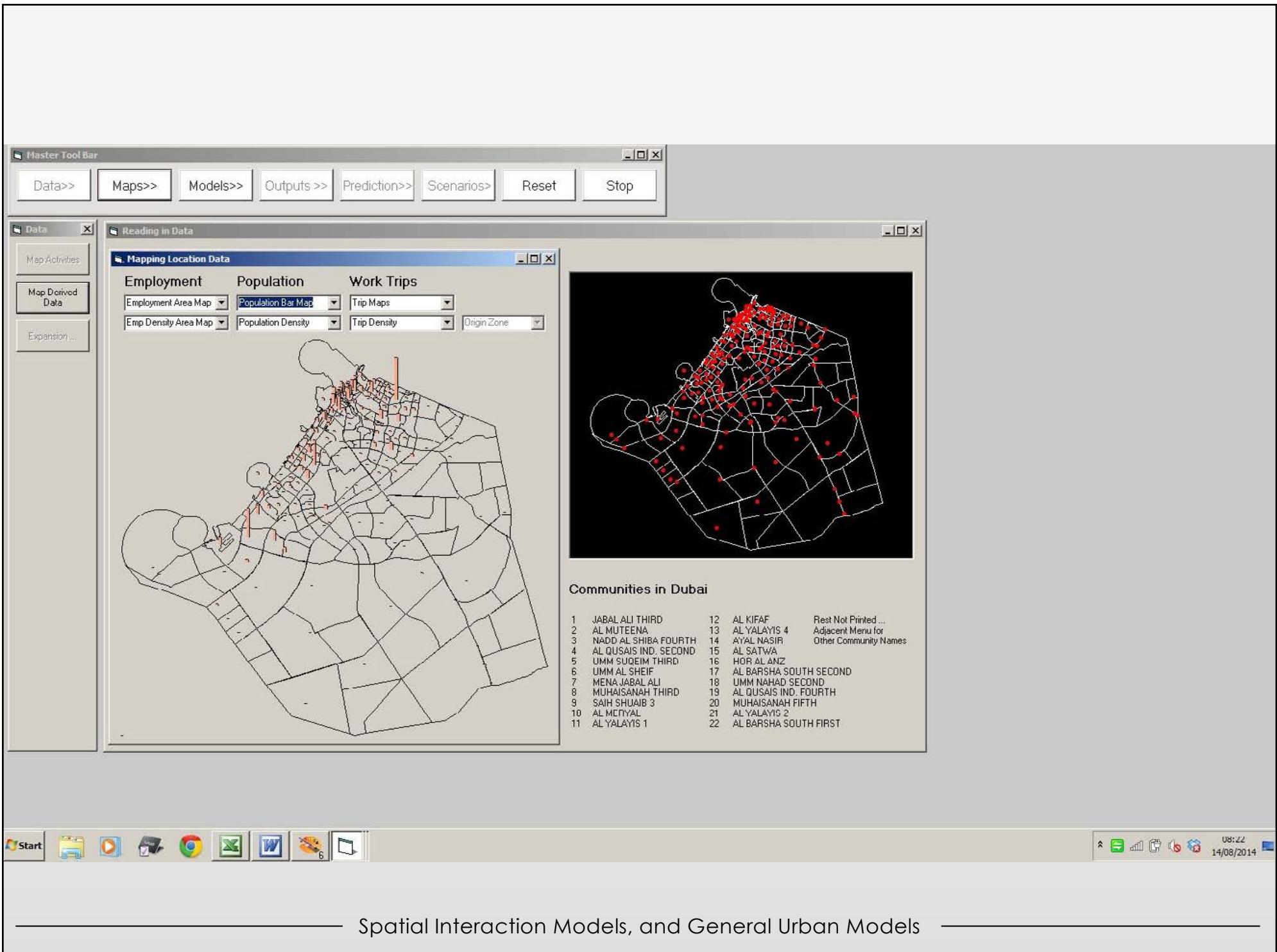
Spatial Interaction Models, and General Urban Models

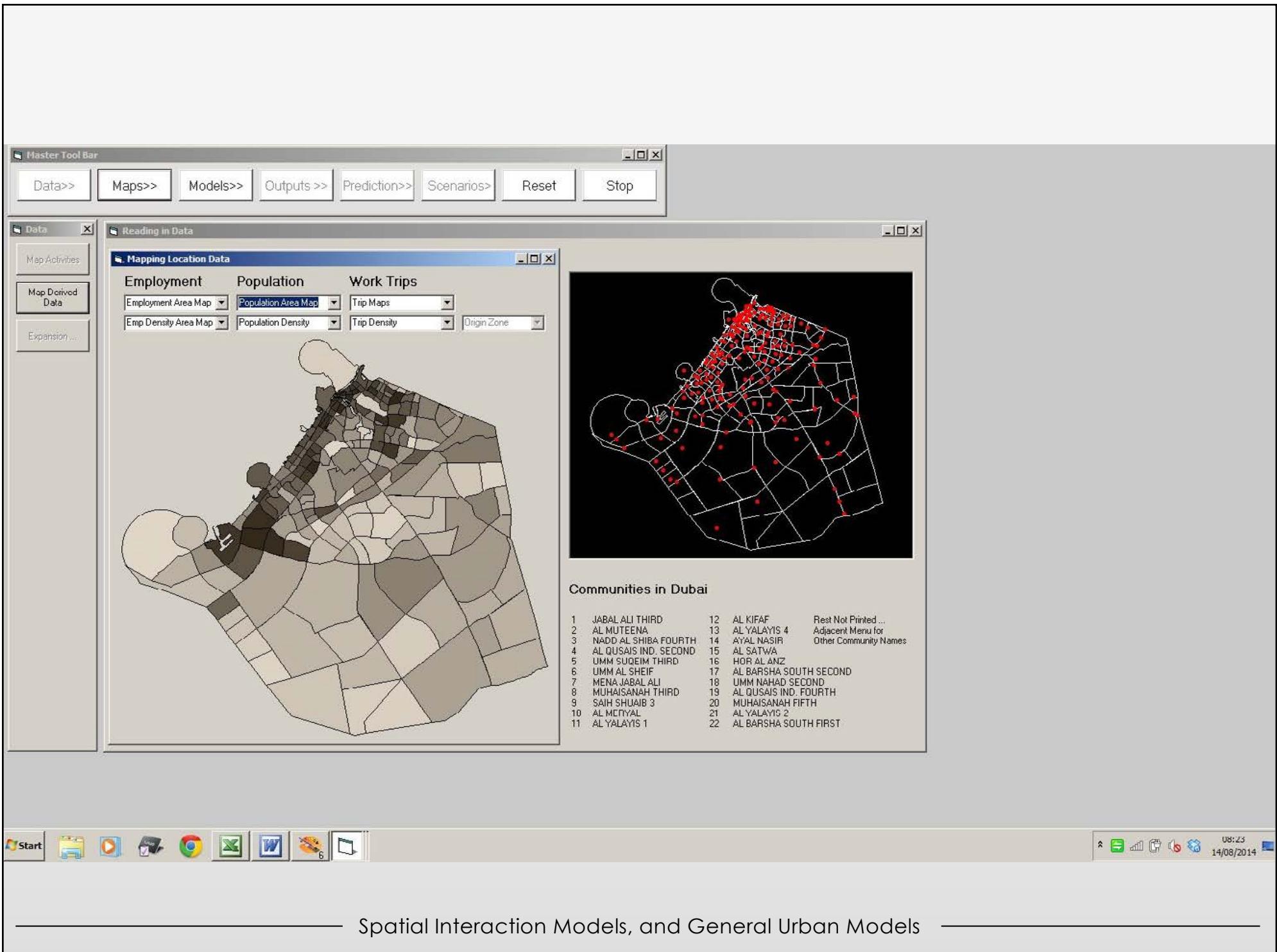


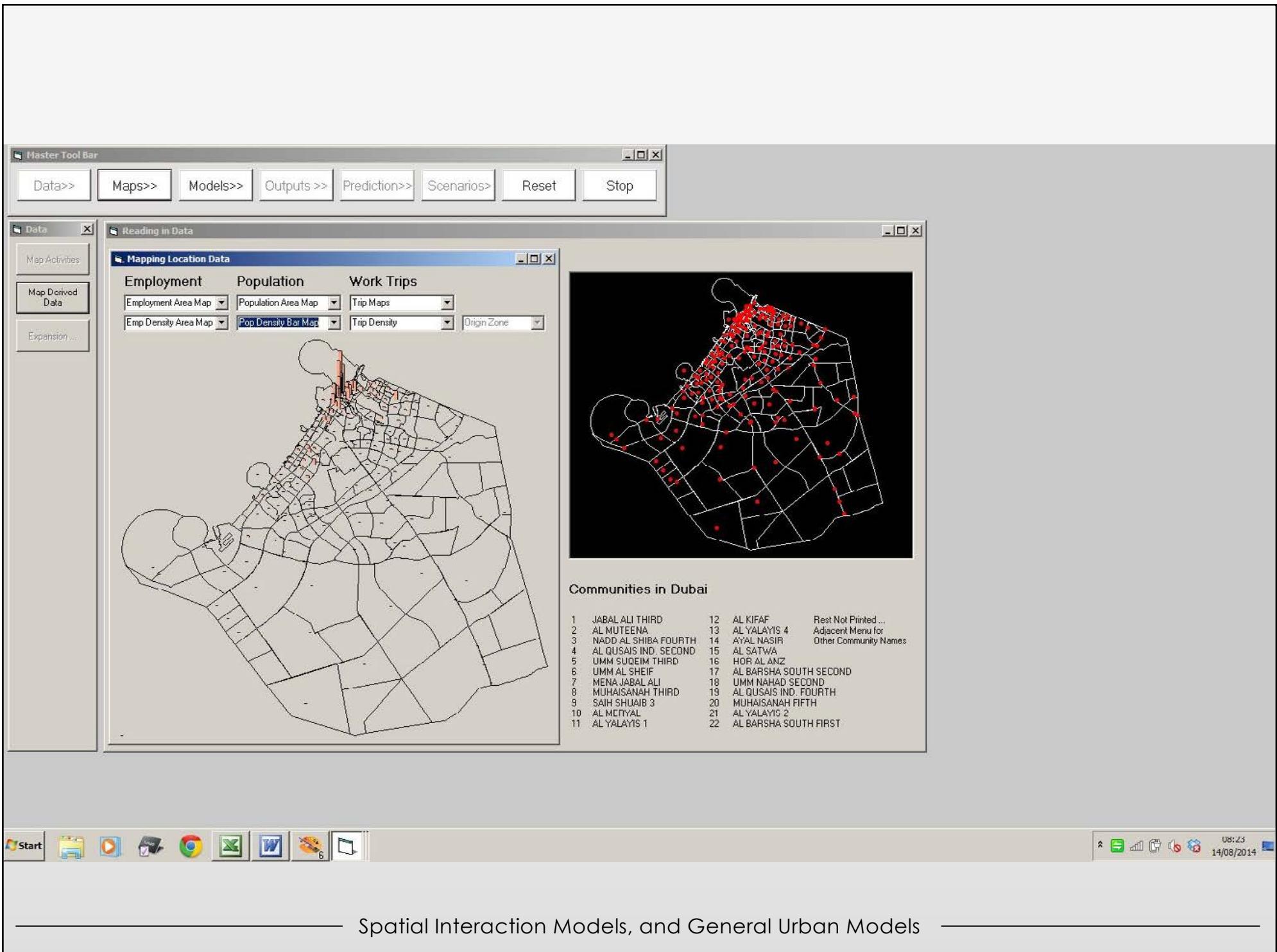


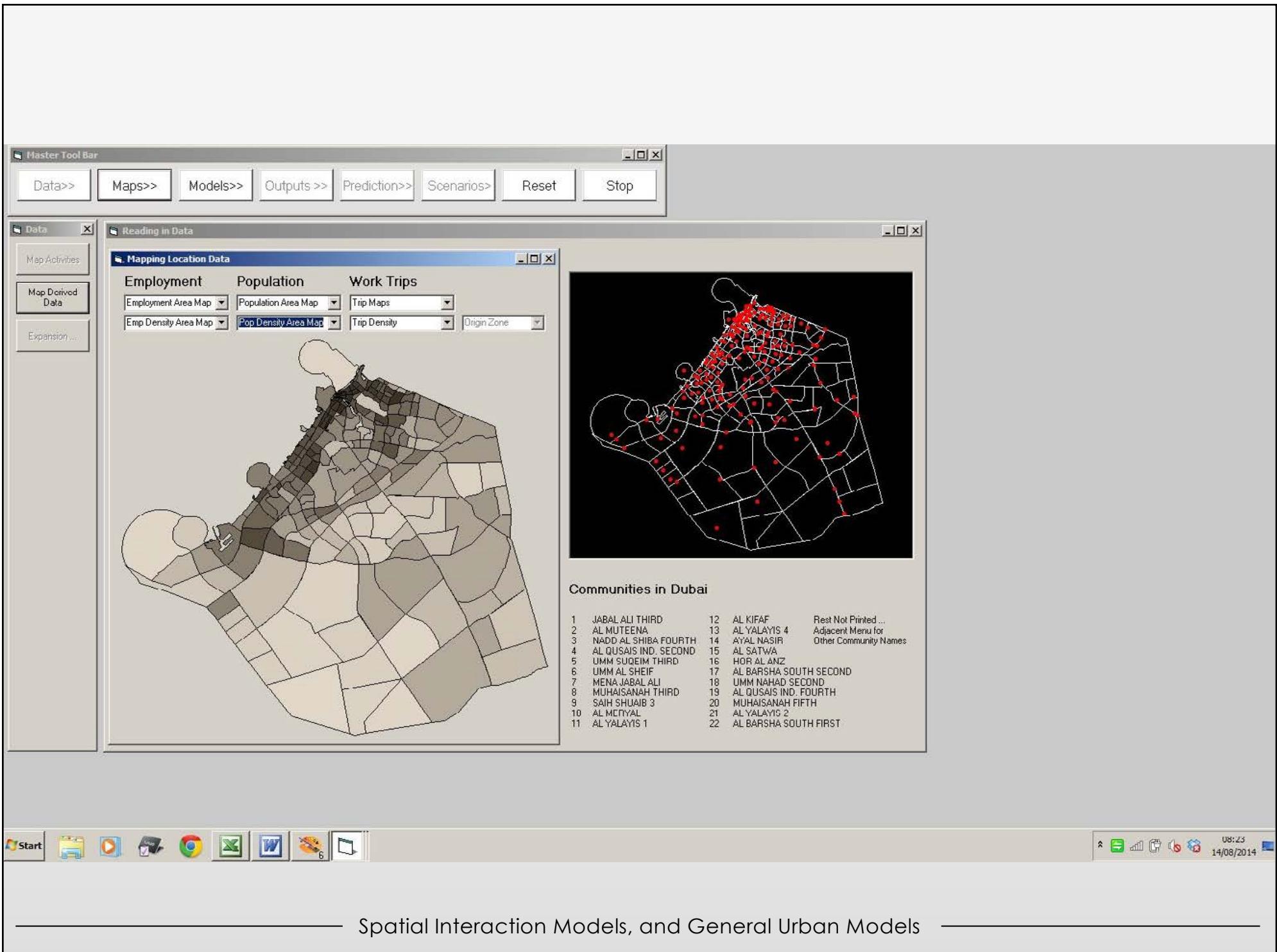


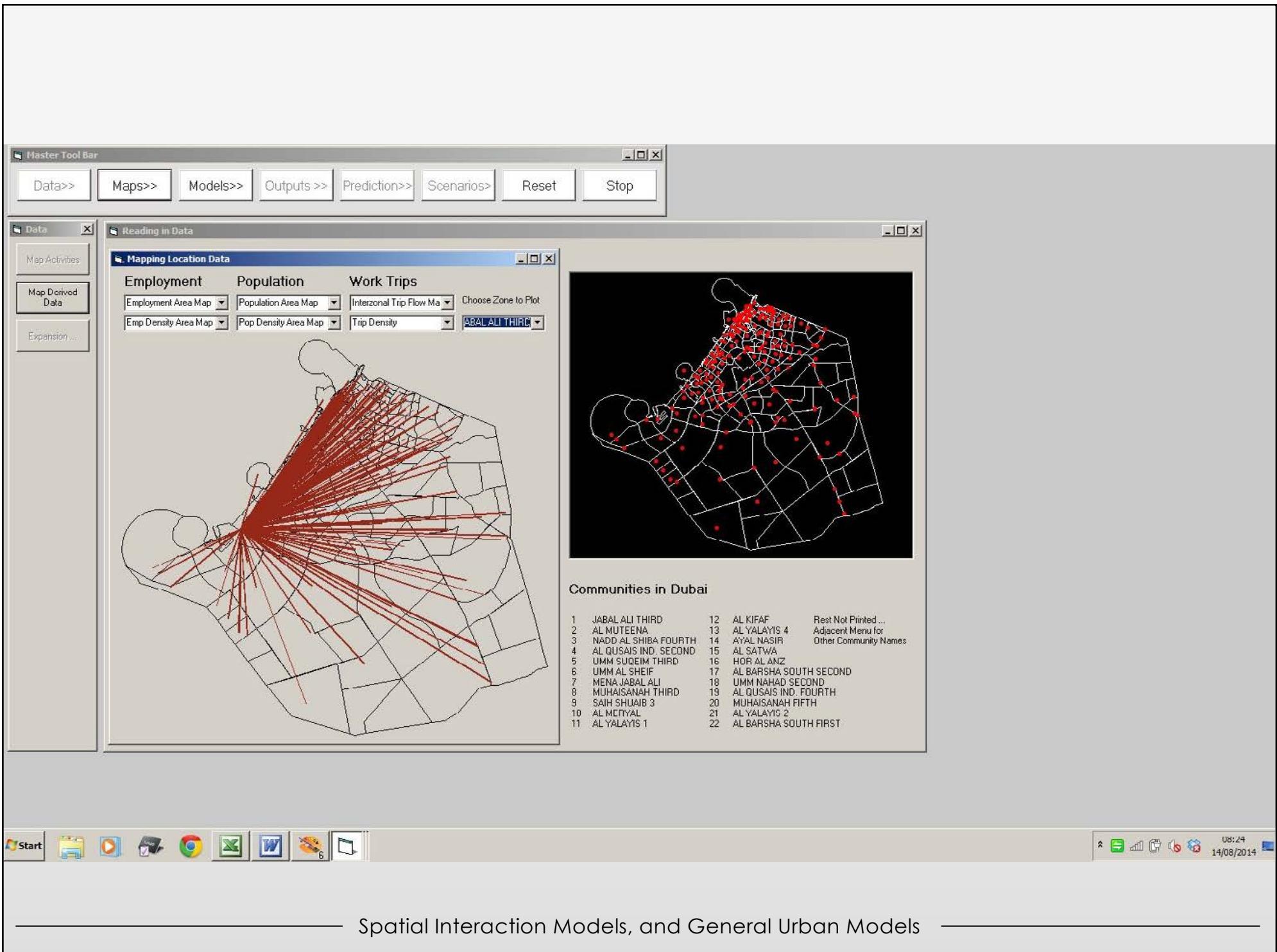


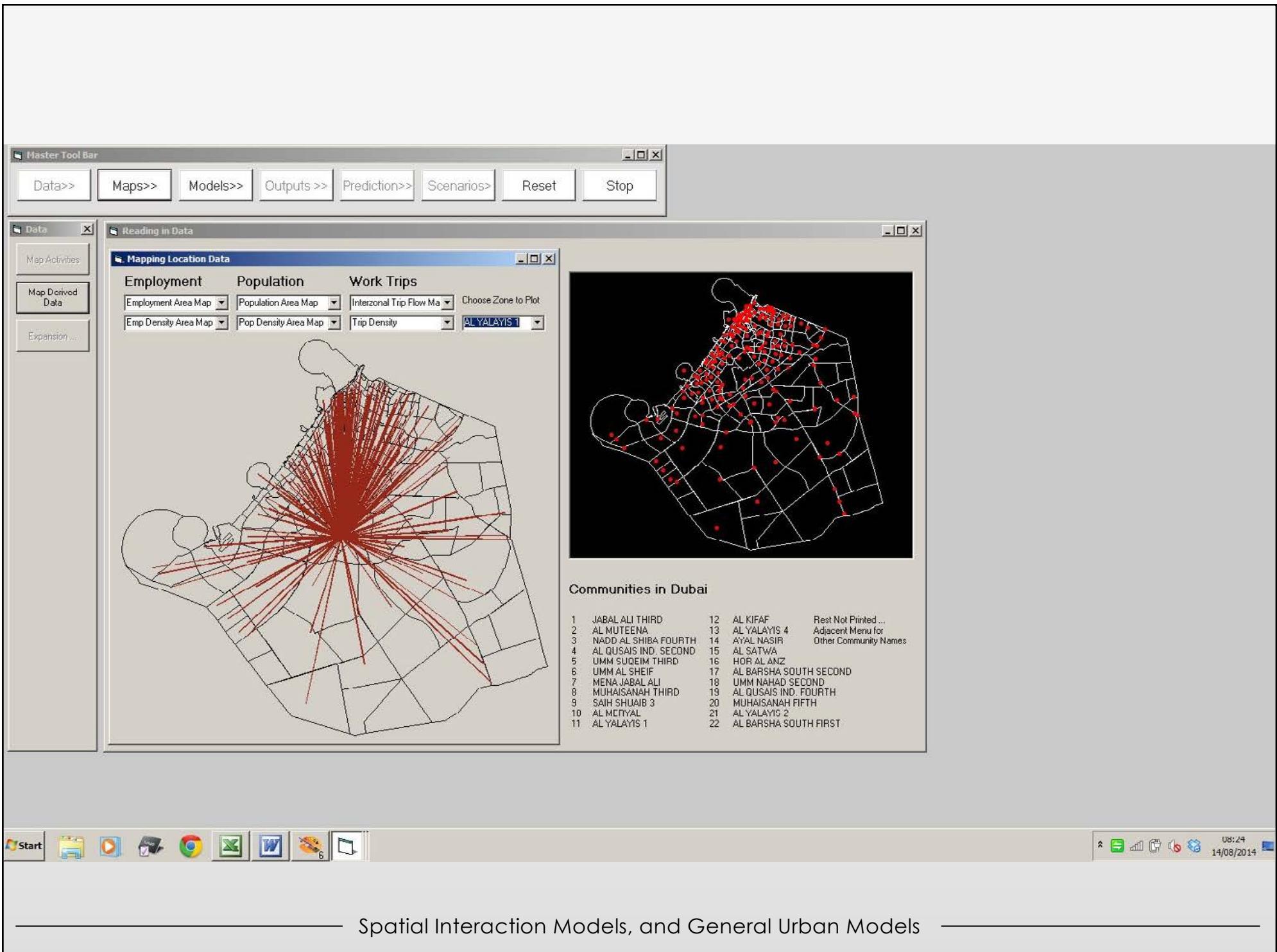


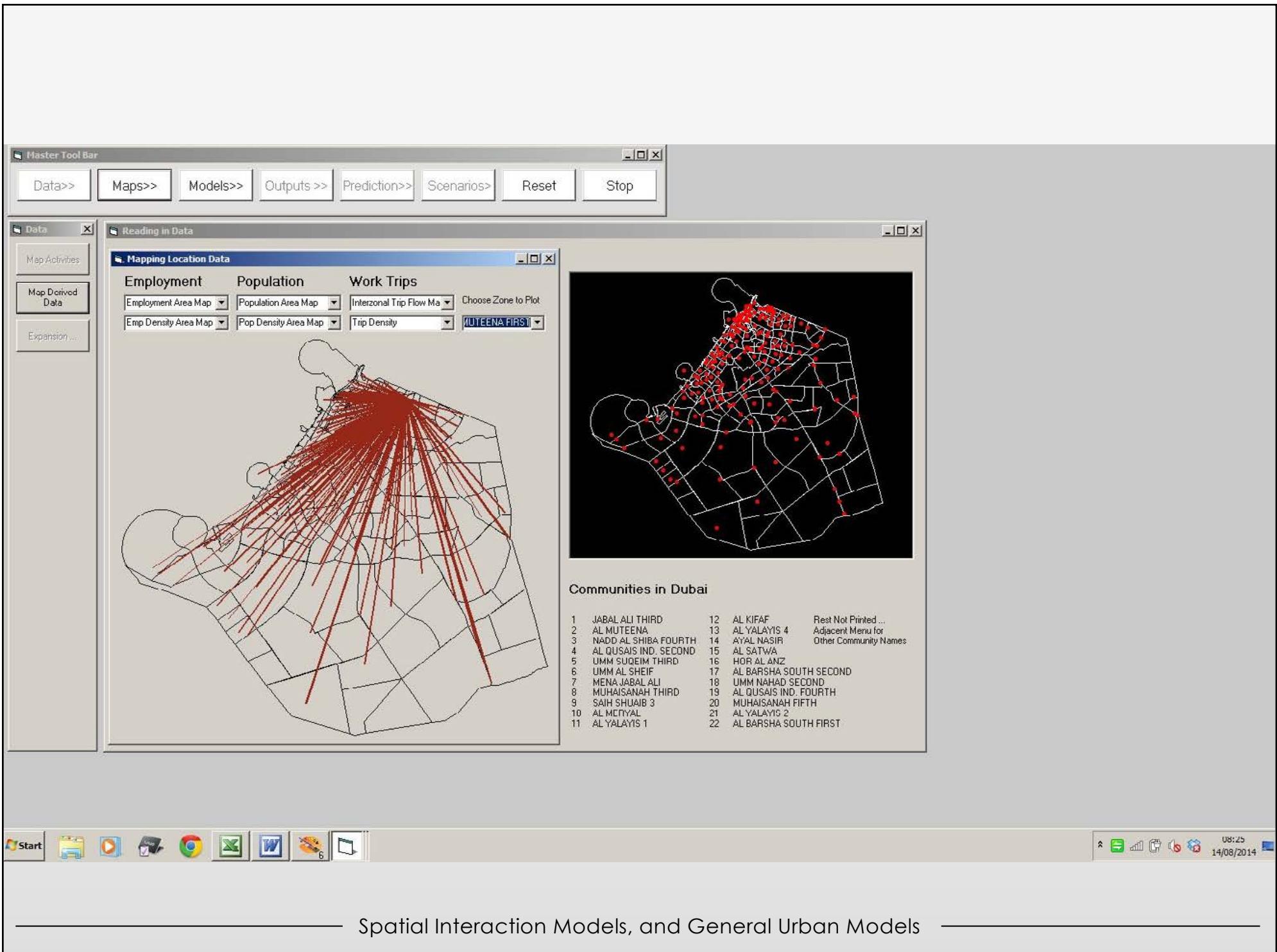


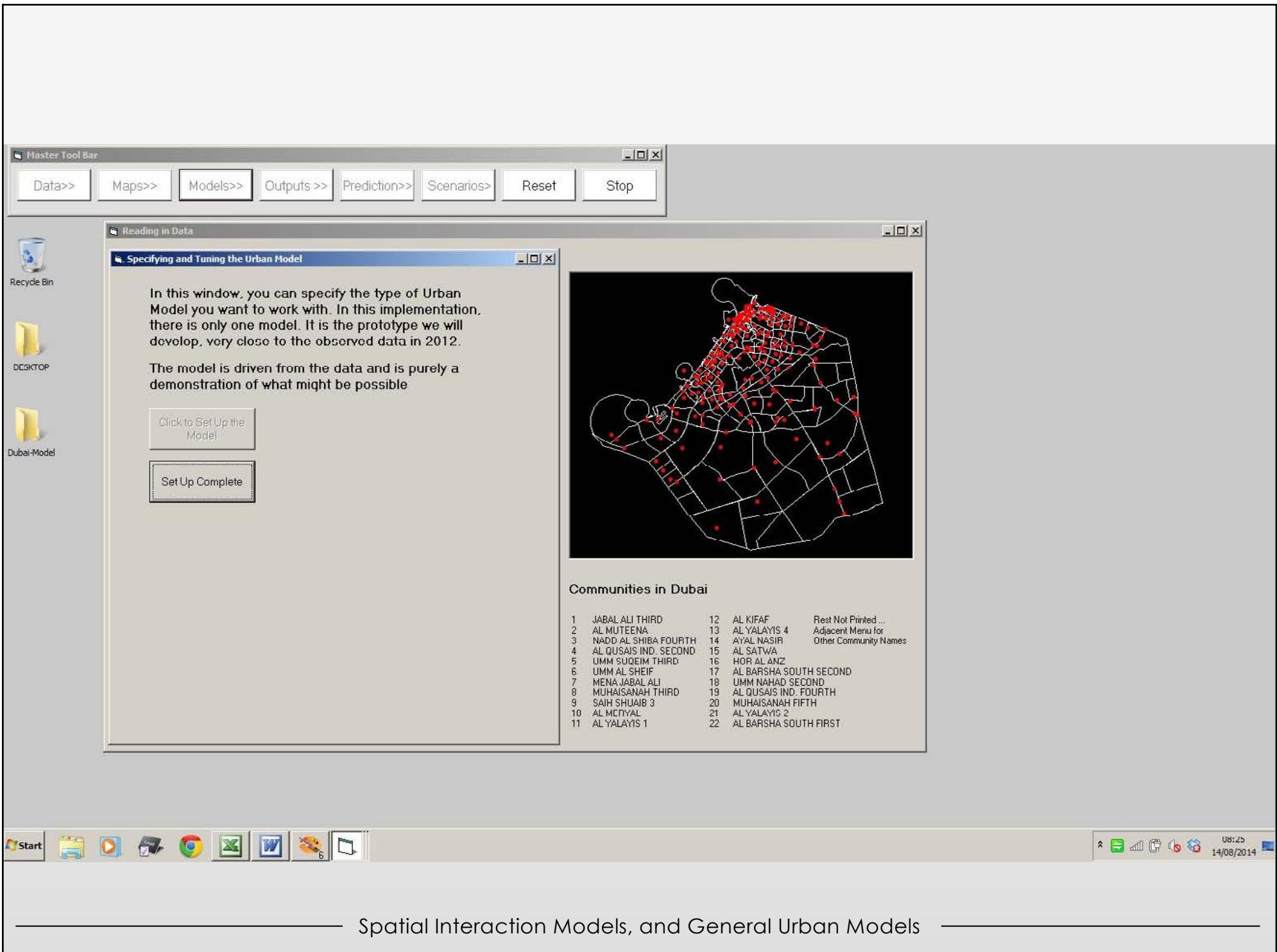


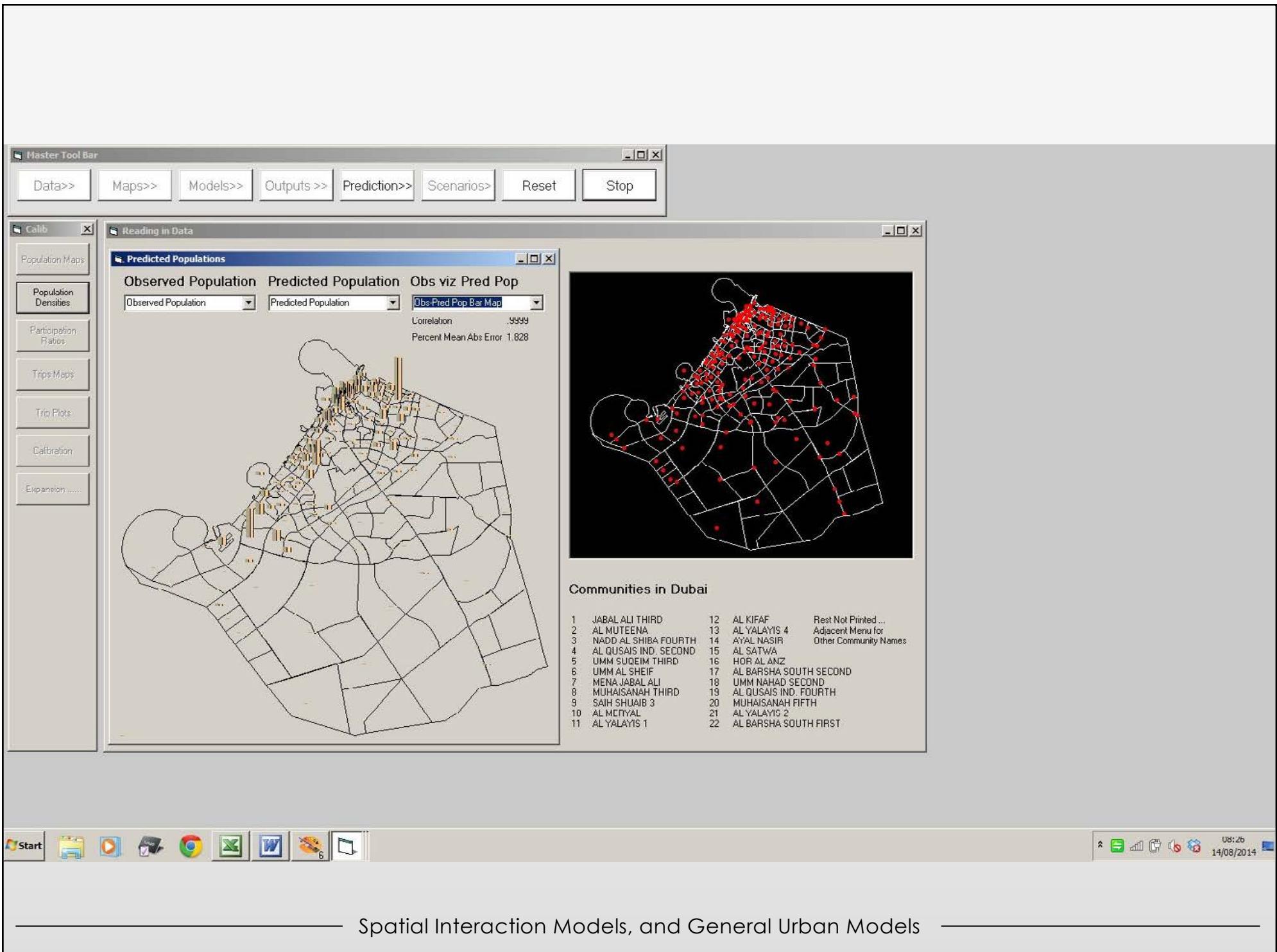












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Predict

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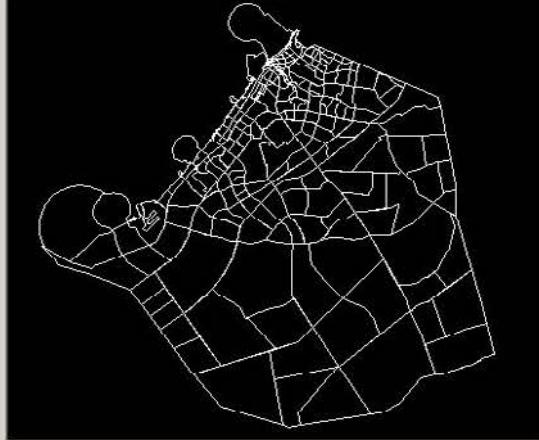
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Start        

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- Stop

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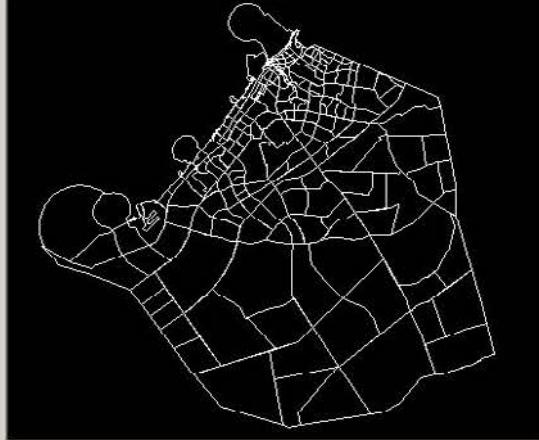
Reading in Data

The Impact of New Retail Activities

Employment Population Work Trips

Employment Maps Population Maps Trip Maps

The Impact of a New City
Centre in Area of AL
HEBIAH SECOND



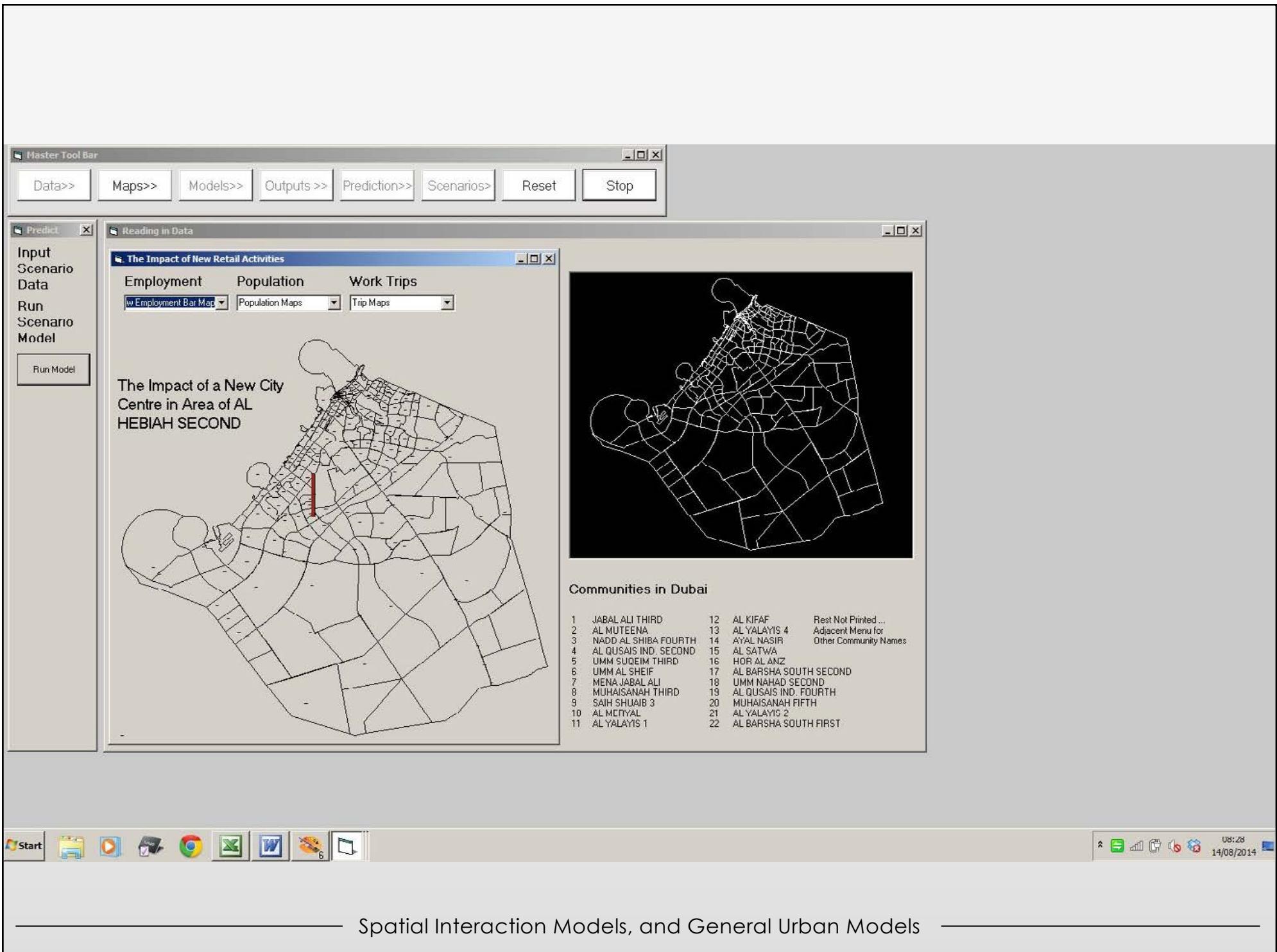
Communities in Dubai

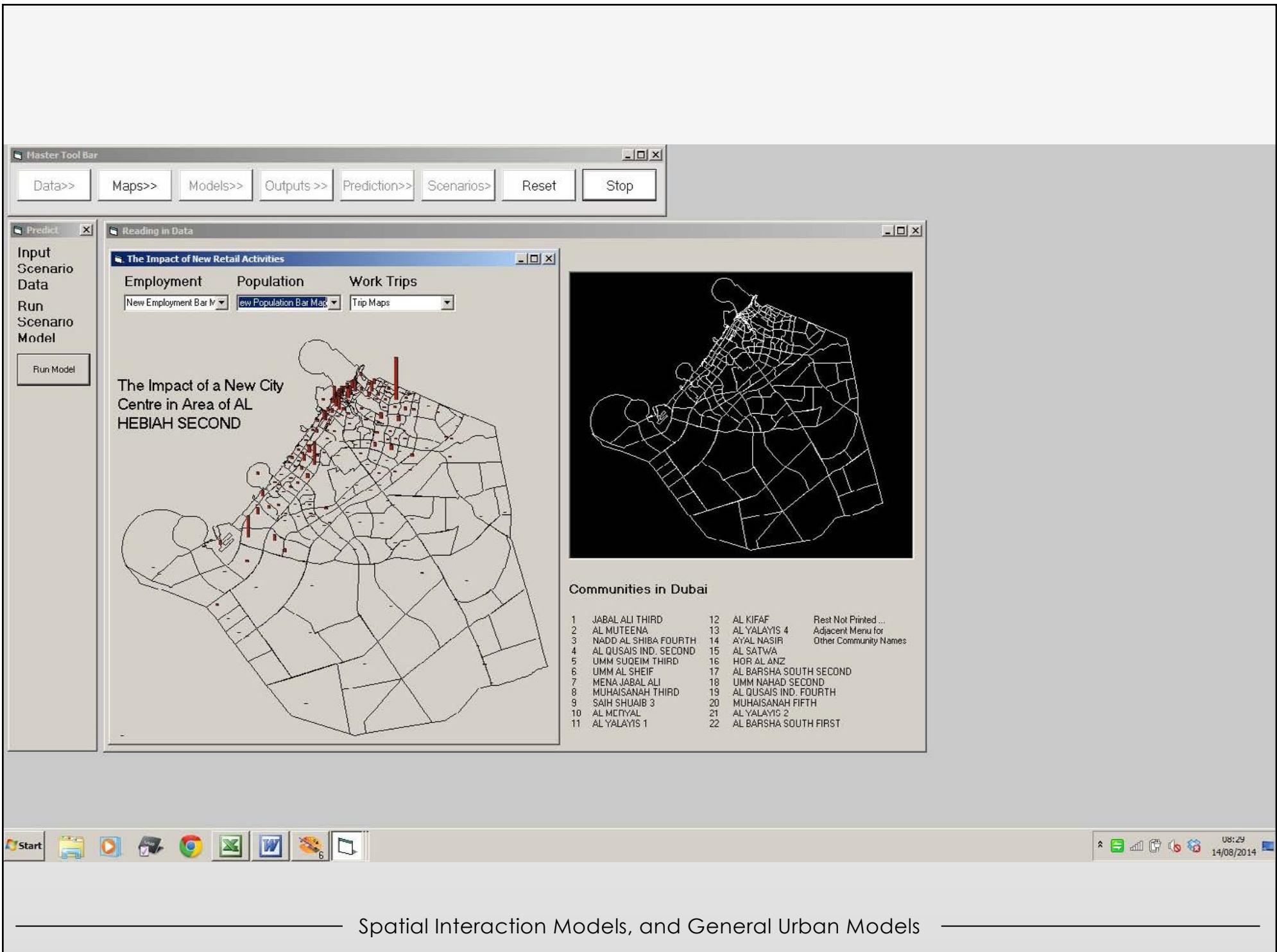
1 JABAL ALI THIRD	12 AL KIFAF	Rest Not Printed ...
2 AL MUTEENA	13 AL YALAYIS 4	Adjacent Menu for
3 NADD AL SHIBA FOURTH	14 ATAYL NASIR	Other Community Names
4 AL QUSAIS IND. SECOND	15 AL SATWA	
5 UMM SUQEIM THIRD	16 HOR AL ANZ	
6 UMM AL SHEIF	17 AL BARSHA SOUTH SECOND	
7 MENA JABAL ALI	18 UMM NAHAD SECOND	
8 MUHAISANAH THIRD	19 AL QUSAIS IND. FOURTH	
9 SAIH SHUAIB 3	20 MUHAISANAH FIFTH	
10 AL MCNYAL	21 AL YALAYIS 2	
11 AL YALAYIS 1	22 AL BARSHA SOUTH FIRST	

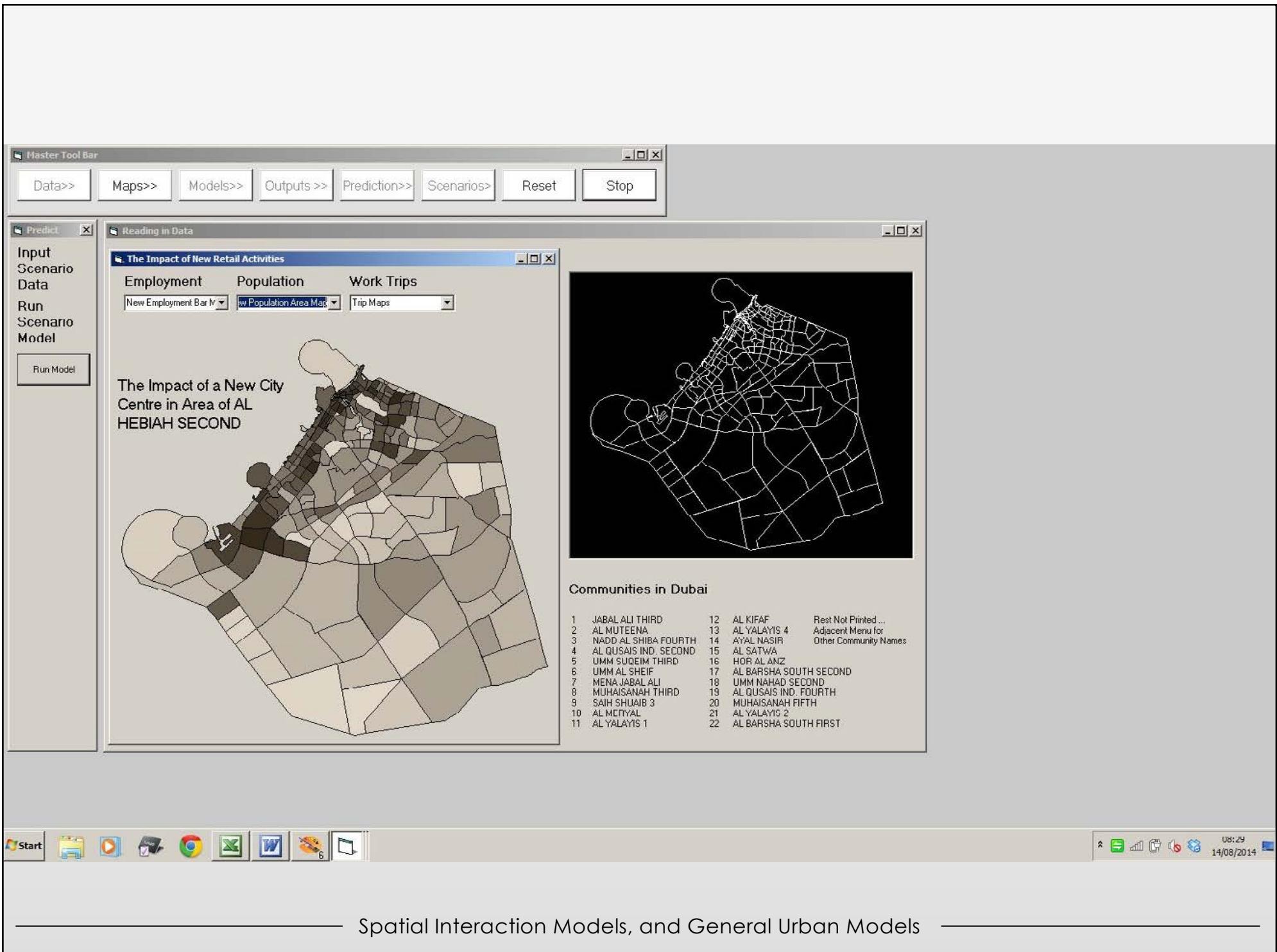
Start My Computer My Pictures Google Chrome Microsoft Word Microsoft Excel Microsoft PowerPoint Microsoft Project Microsoft Access Microsoft Publisher

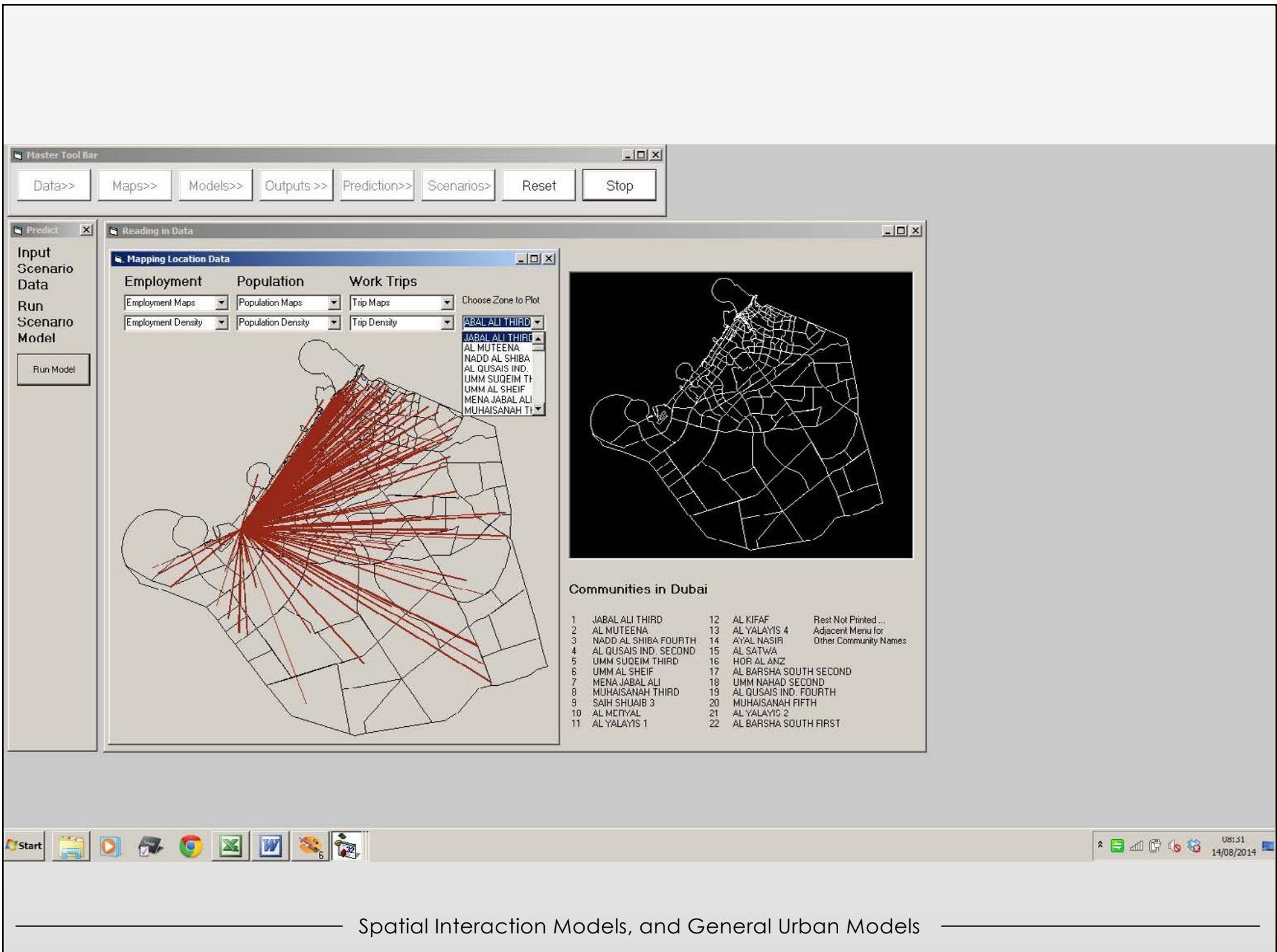
08:28 14/08/2014

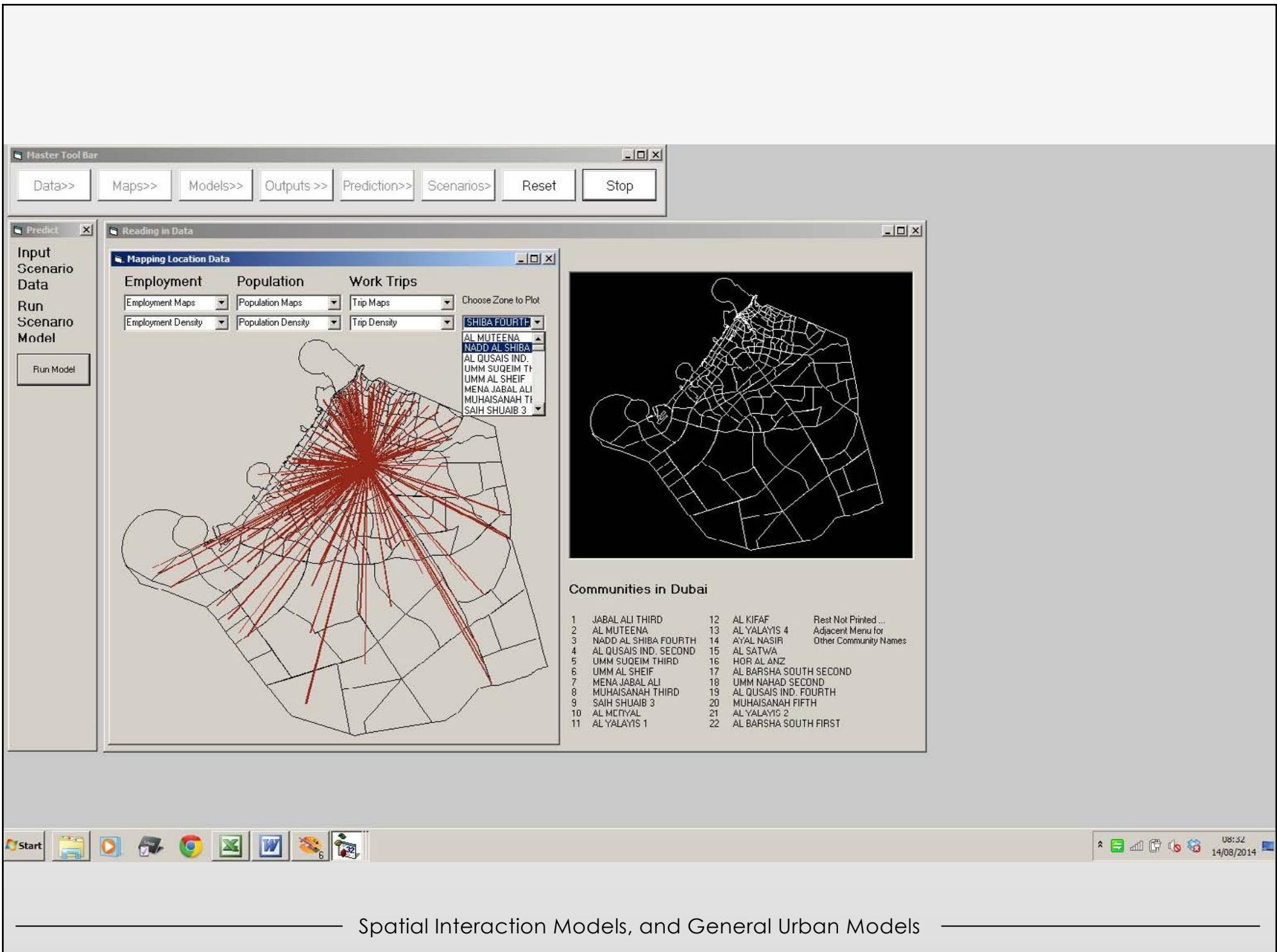
Spatial Interaction Models, and General Urban Models

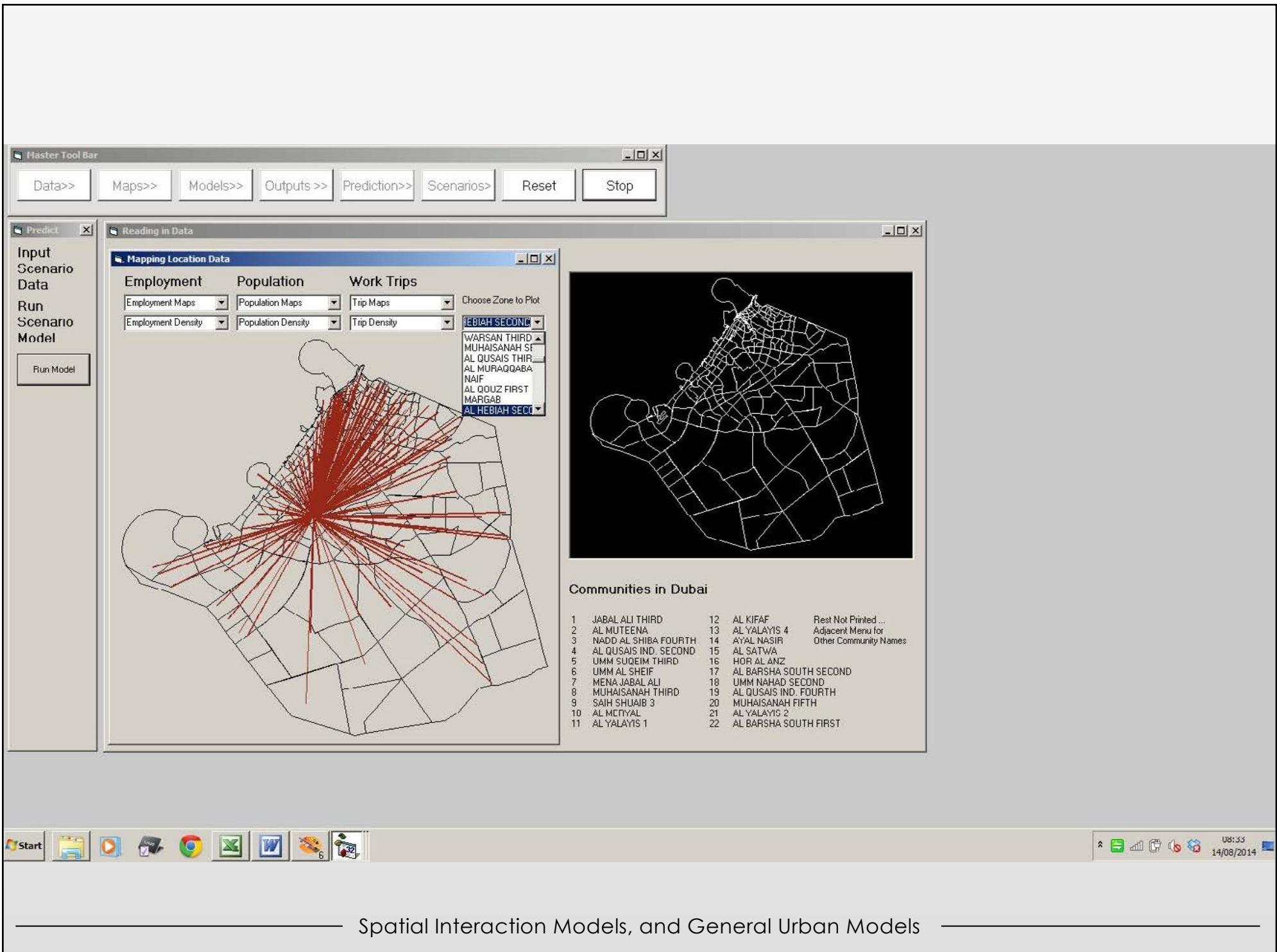








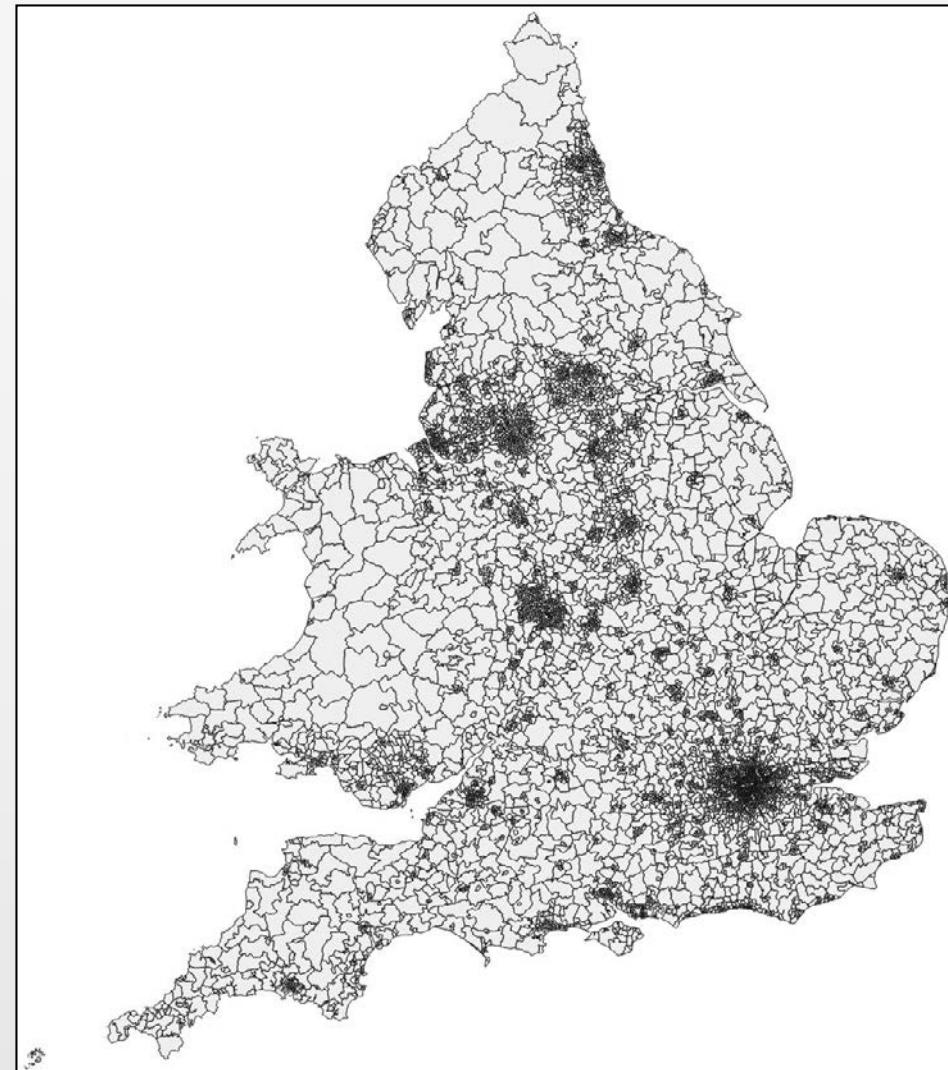




QUANT

stands for

Quantitative Urban Analytics
forecasTing



<http://quant.casa.ucl.ac.uk/quant2/>

Our current QUANT model is only one sector – simulating flows from employment to residential population sector $T_{ij}(t)$. But we have three modes k of transport, road, rail and bus that give us three sets of trips/flows T_{ij}^k

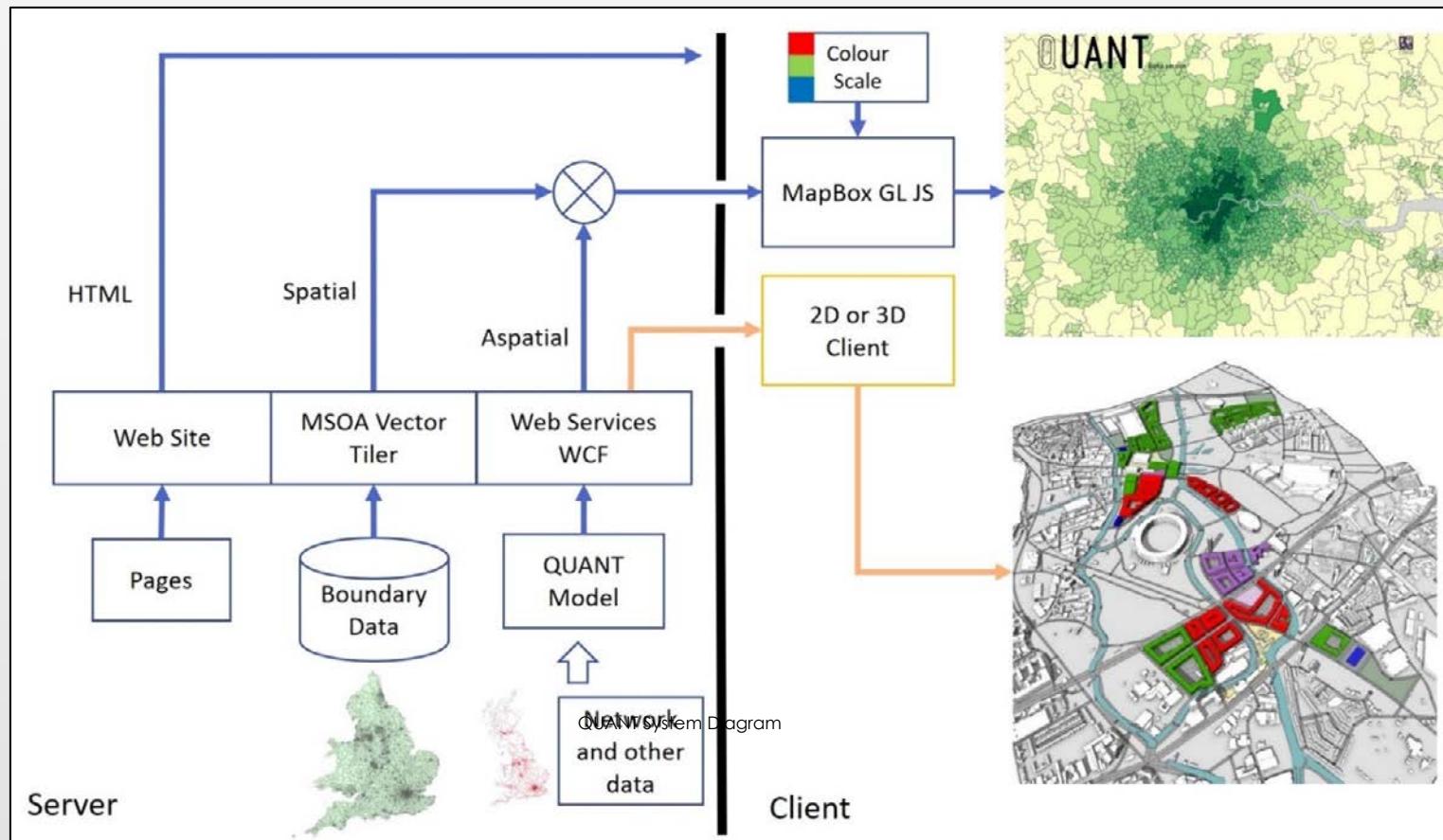
Now our model predicts flows where each model competes for trips relative to their transport costs c_{ij}^k and the model is thus

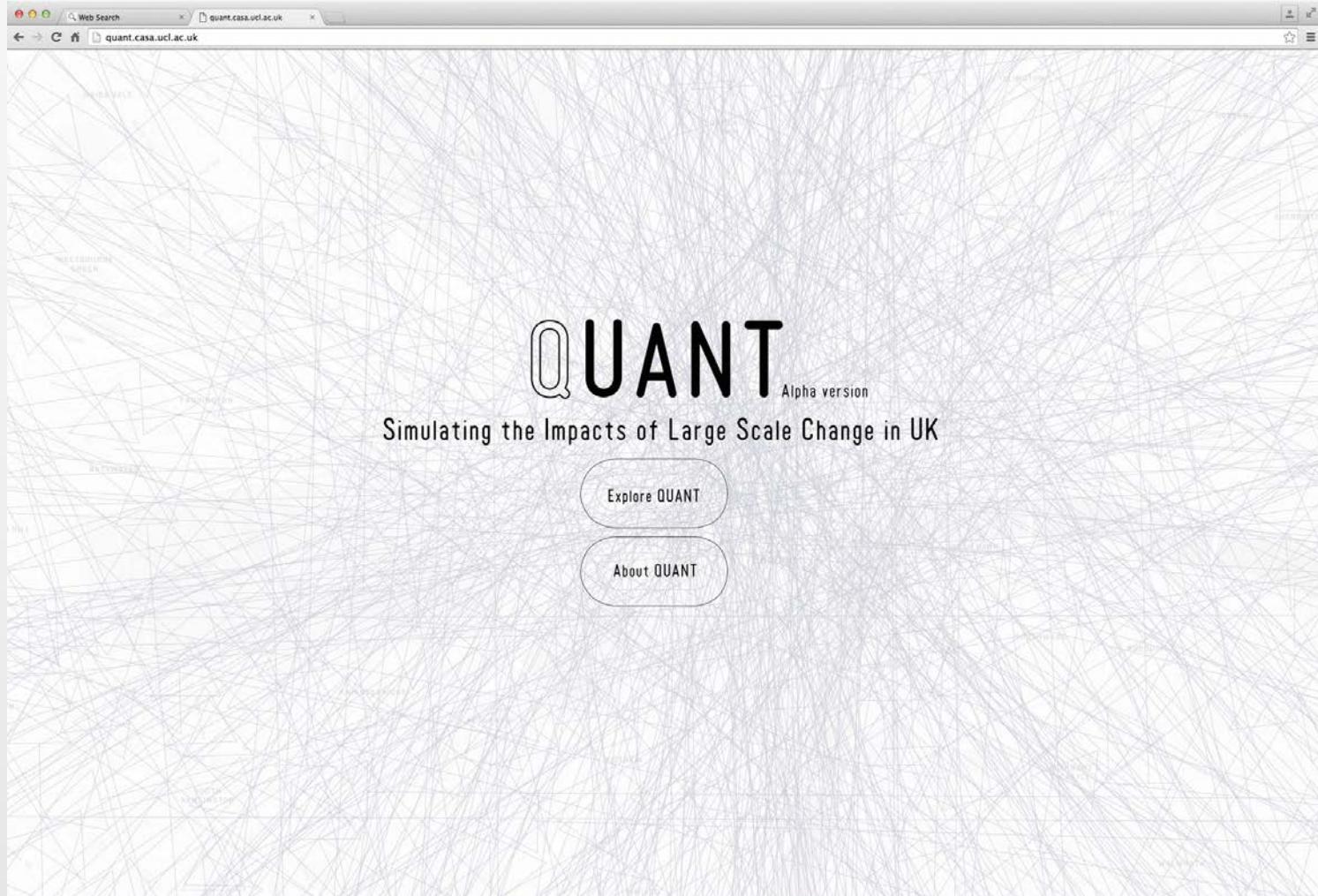
$$\sum_j \sum_k T_{ij}^k = O_i \text{ singly constrained}$$

$$T_{ij}^k = A_i O_i F_j^\alpha \exp(-\beta c_{ij}^k) \text{ modal trips k}$$

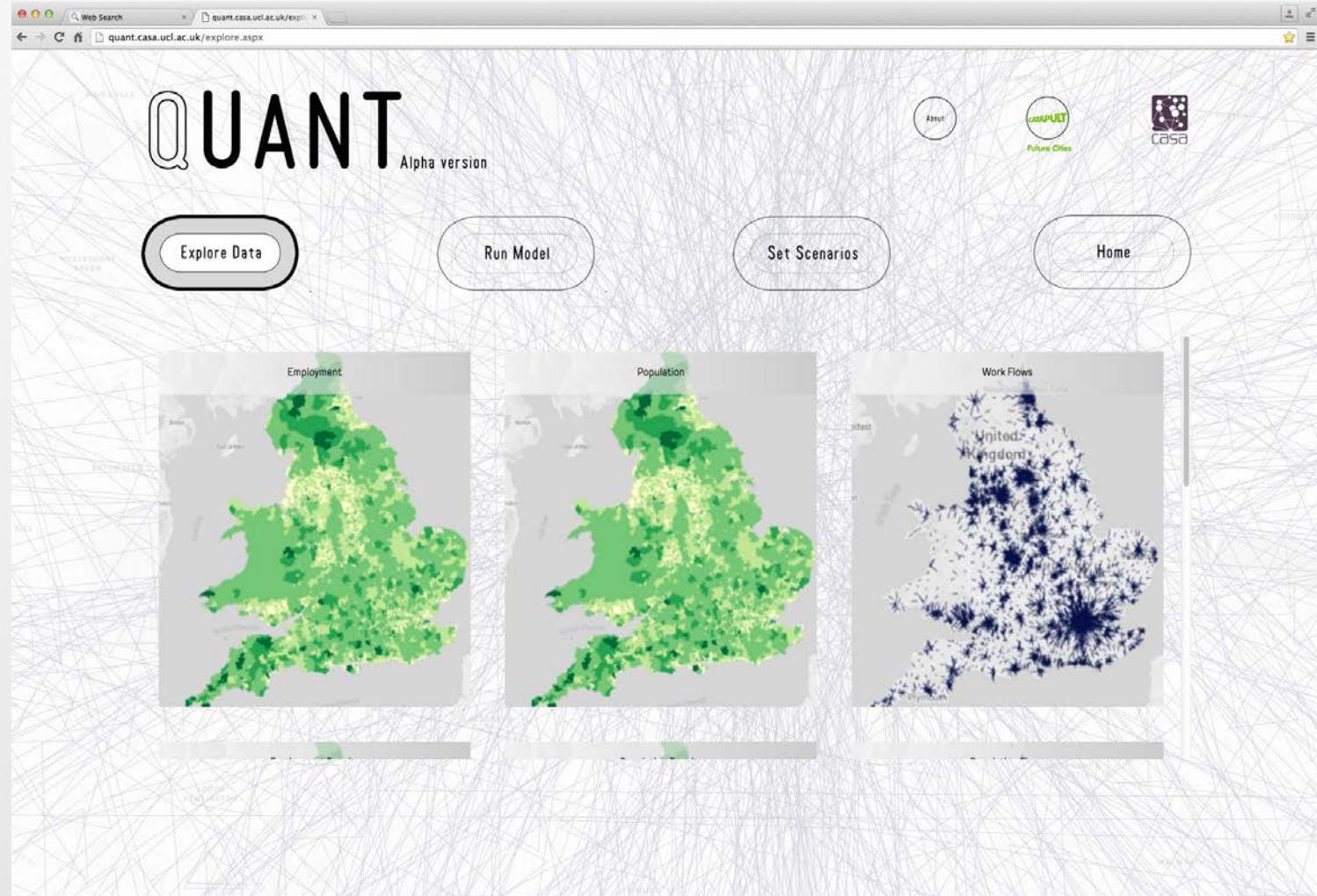
$$\frac{T_{ij}^{k_1}}{T_{ij}^{k_2}} = \frac{\exp(-\beta c_{ij}^{k_1})}{\exp(-\beta c_{ij}^{k_2})} \text{ modal split competition}$$

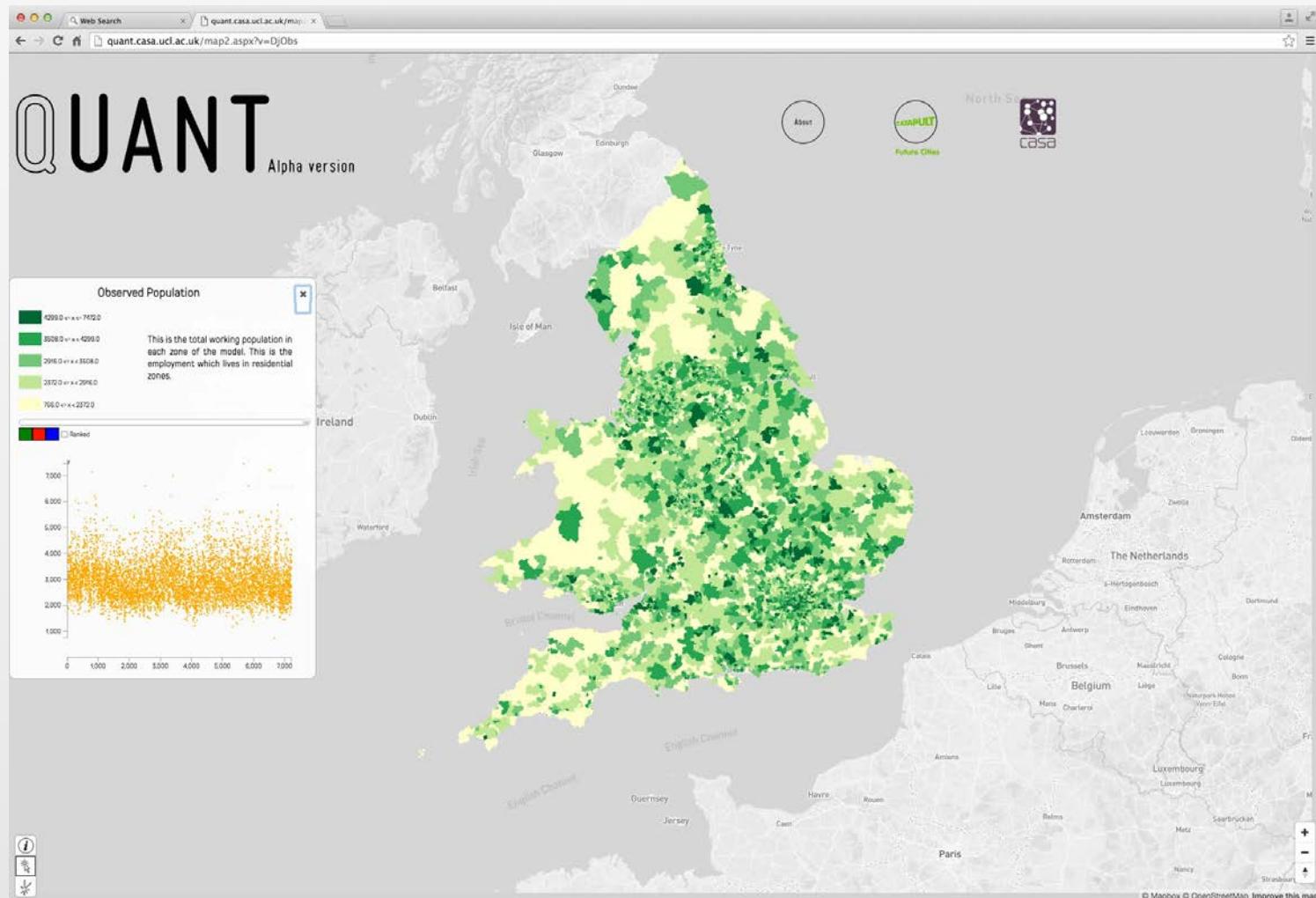
Our current QUANT model has 8436 MSOAs, giving about 71 million potential trips for each of three modes. It has three modal transport networks and employment and population density and constraints posed by green belts etc



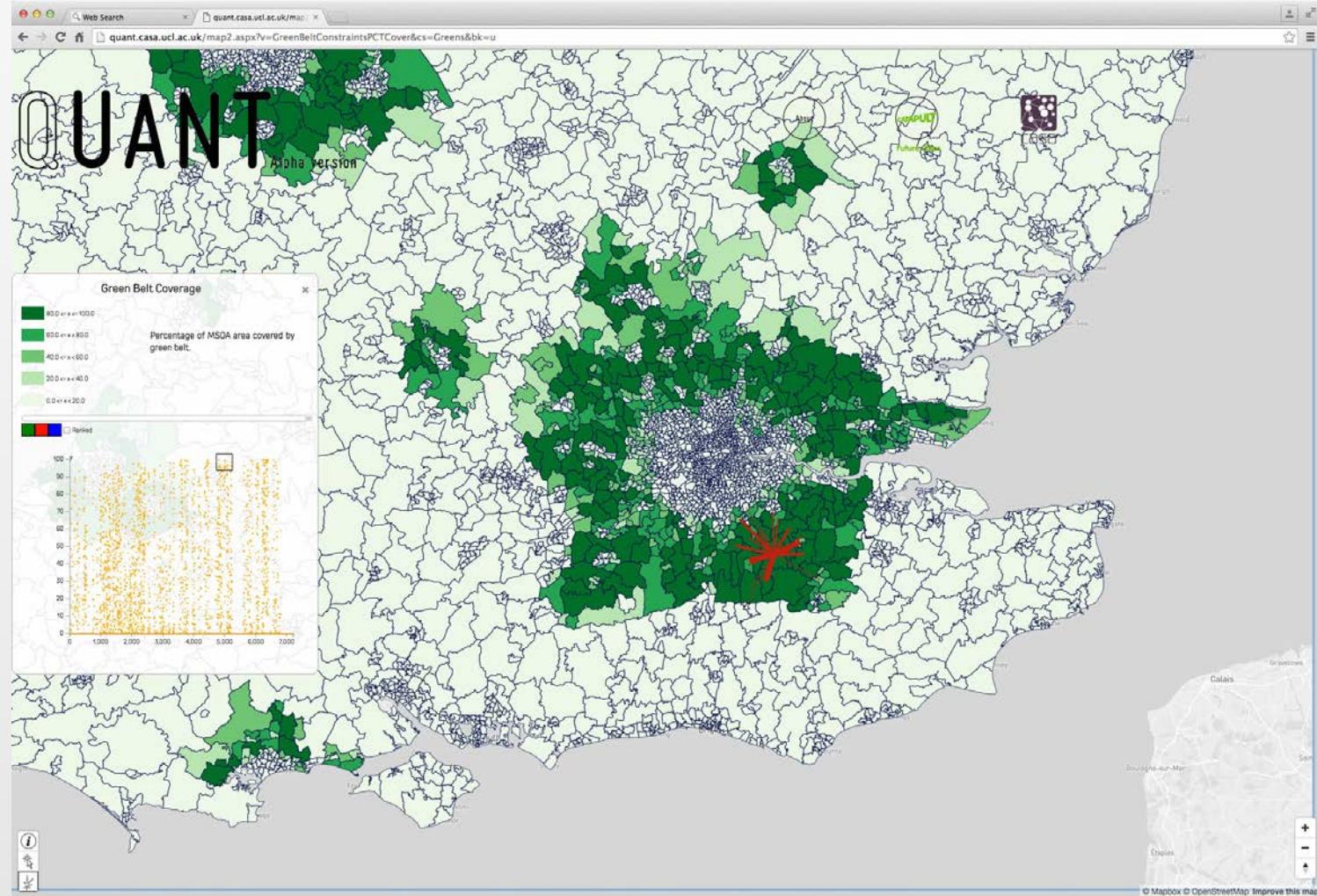


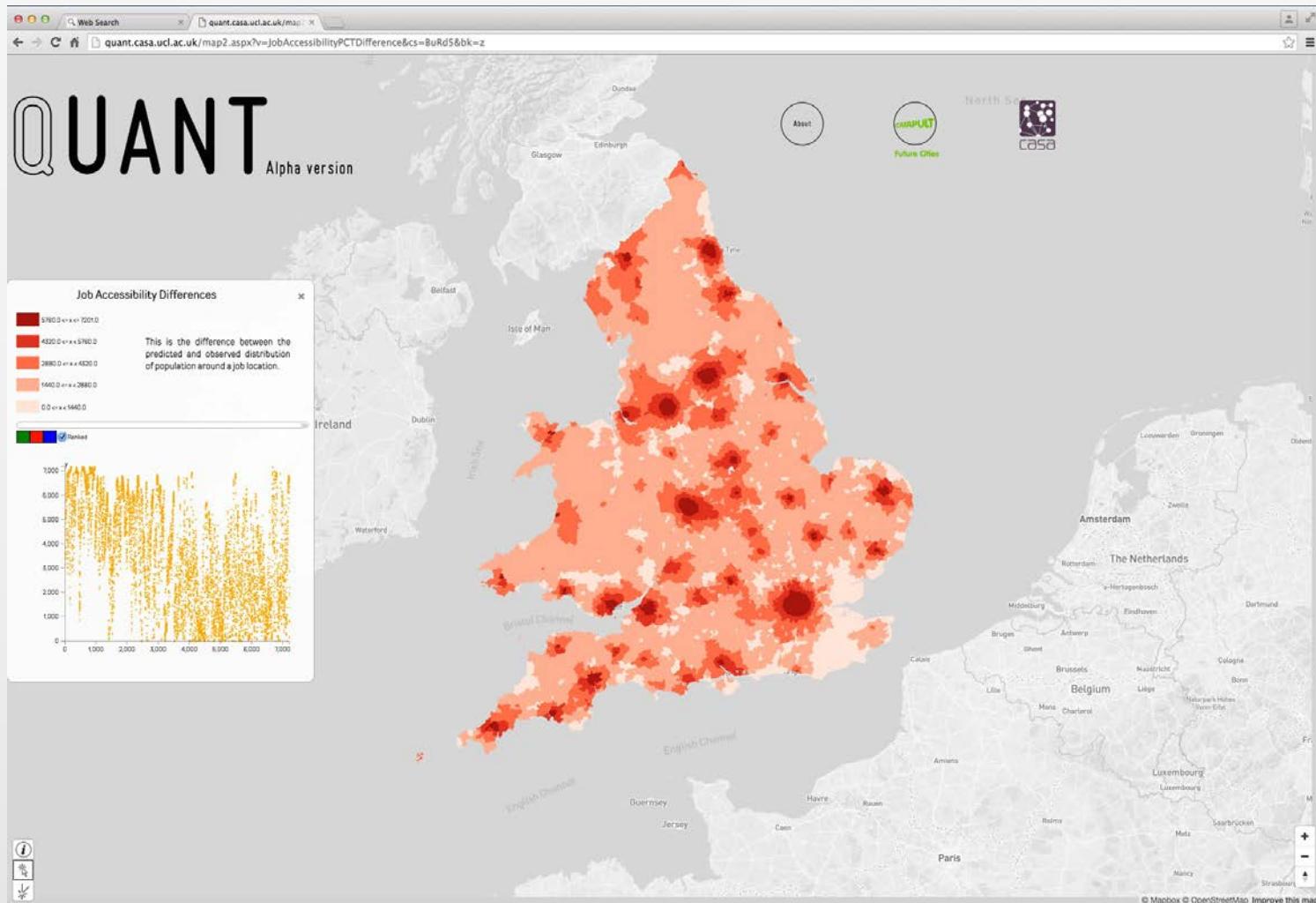


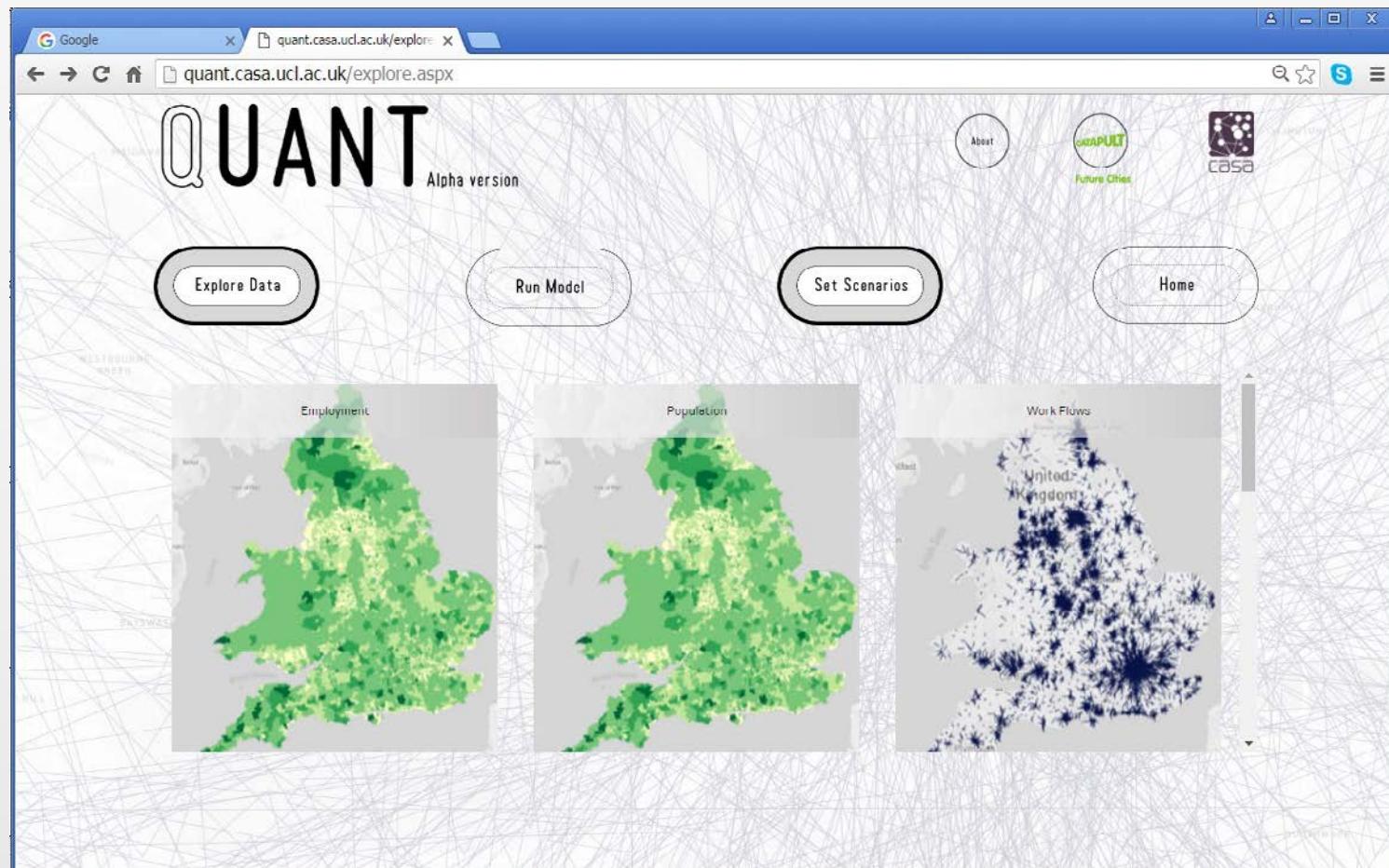


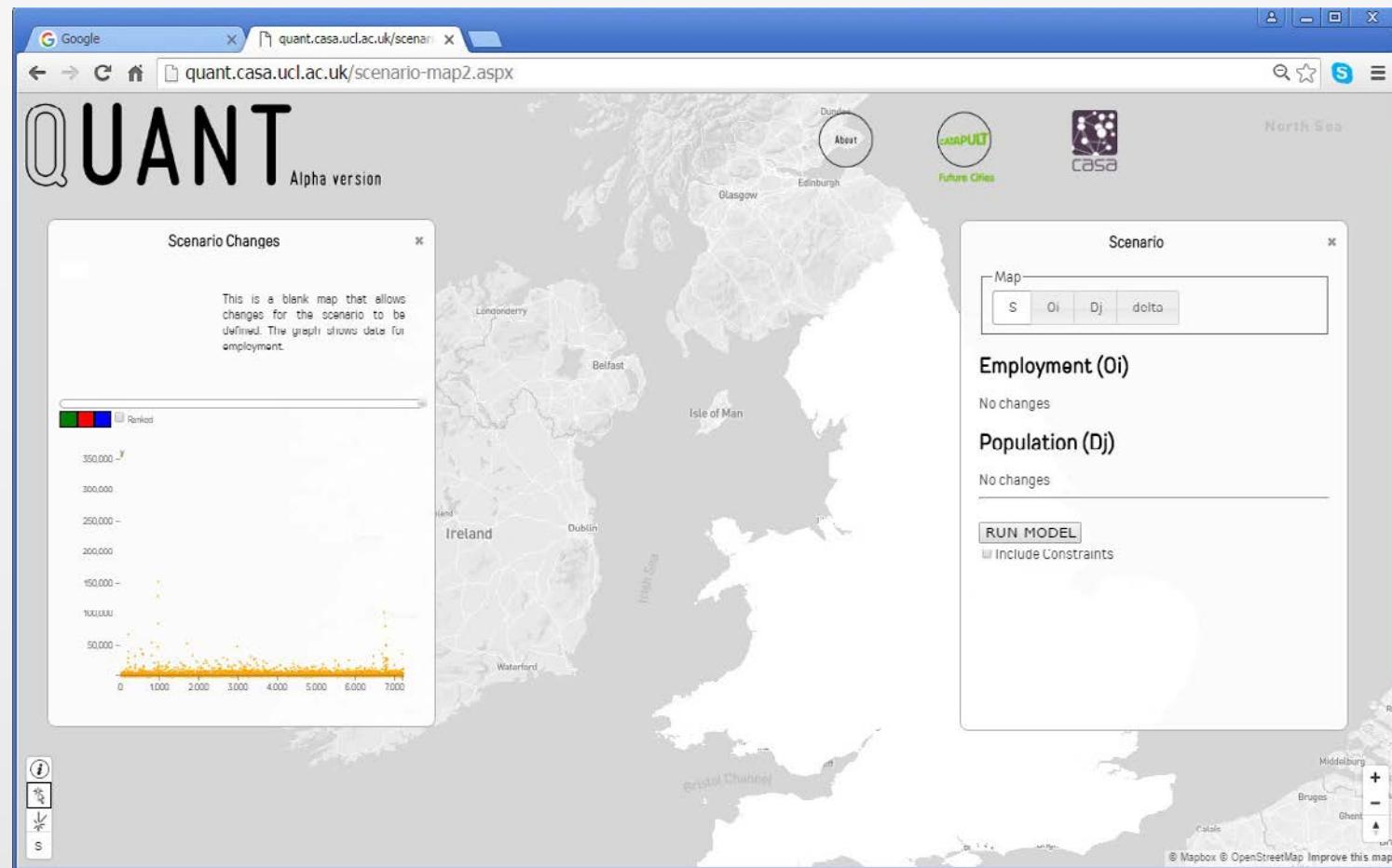


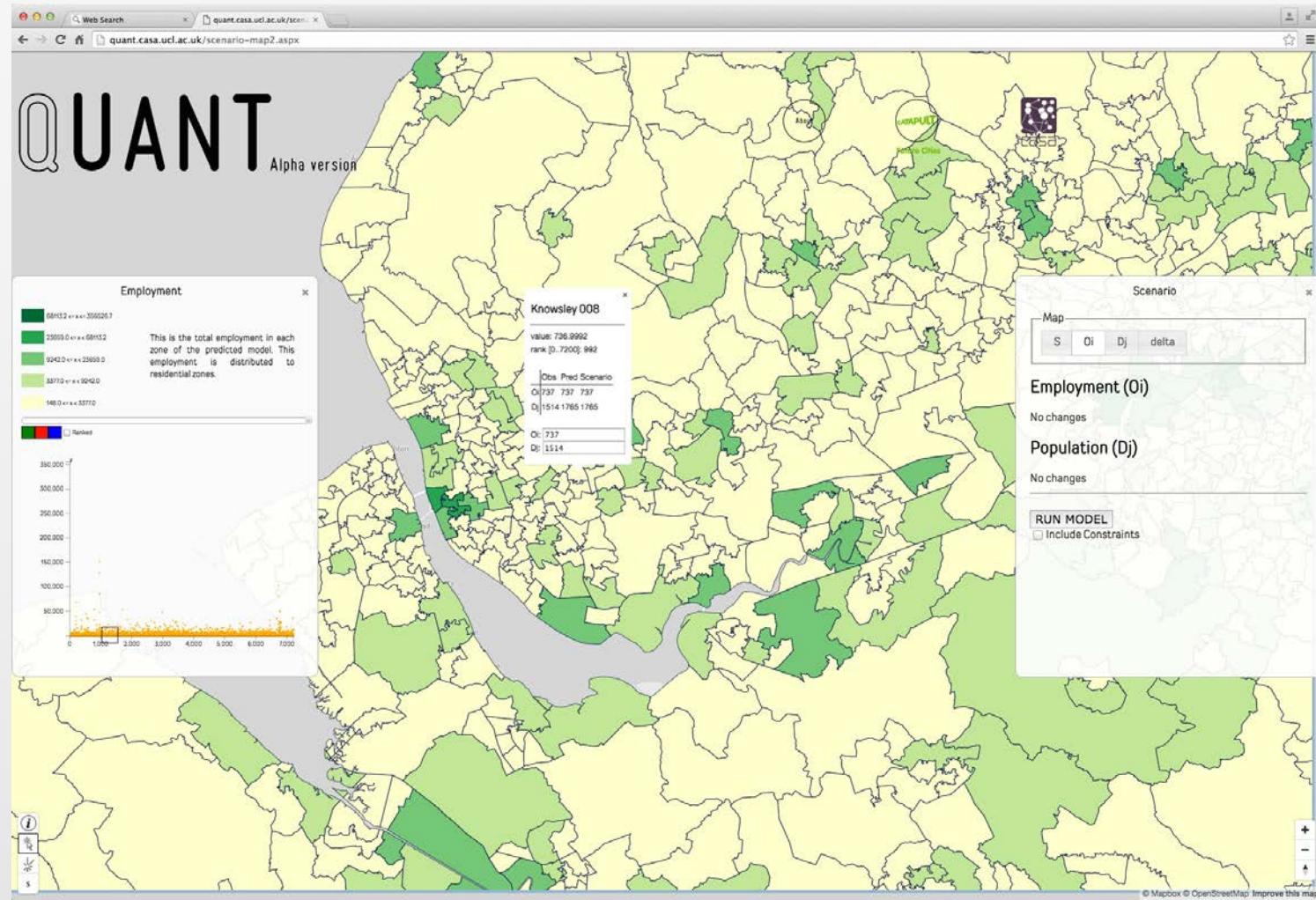


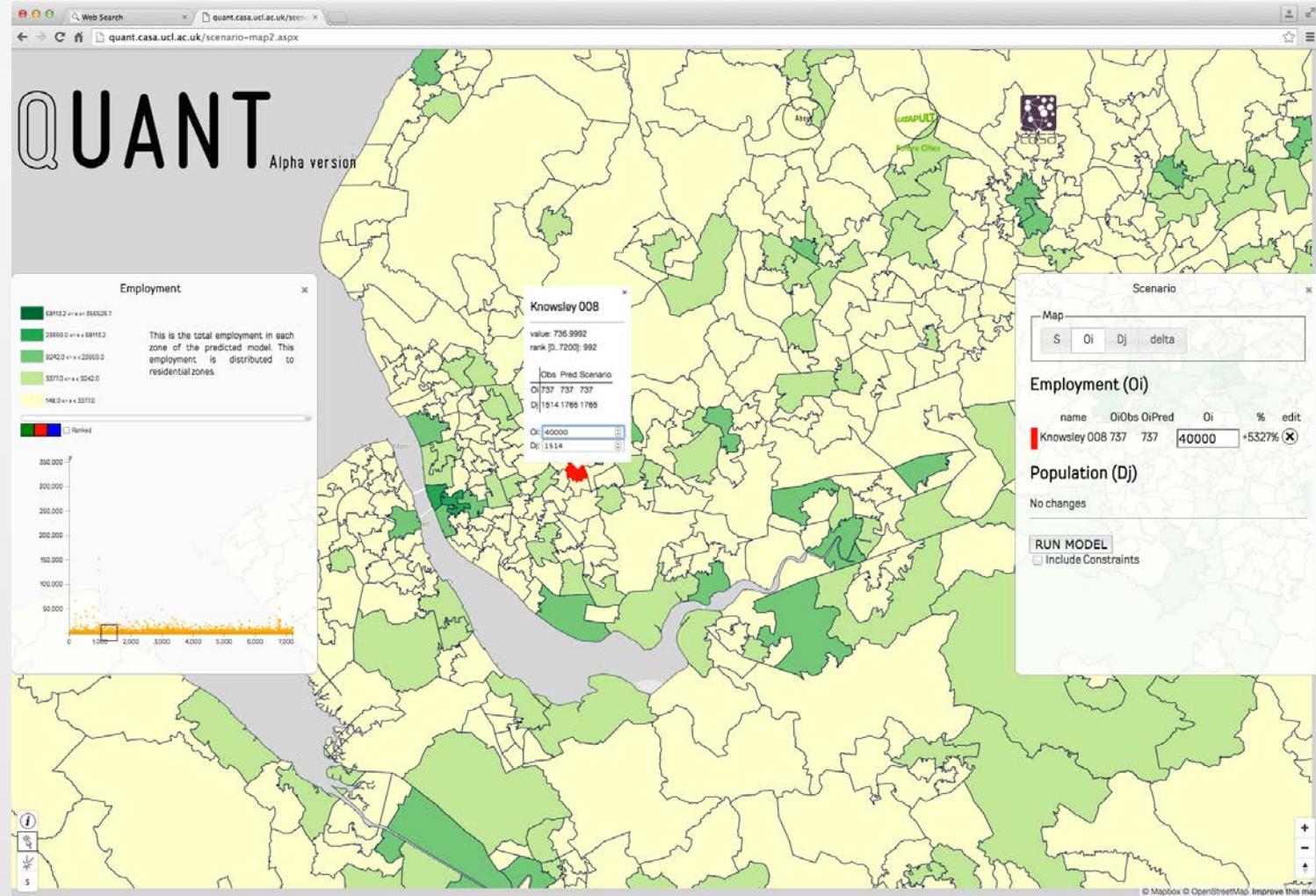


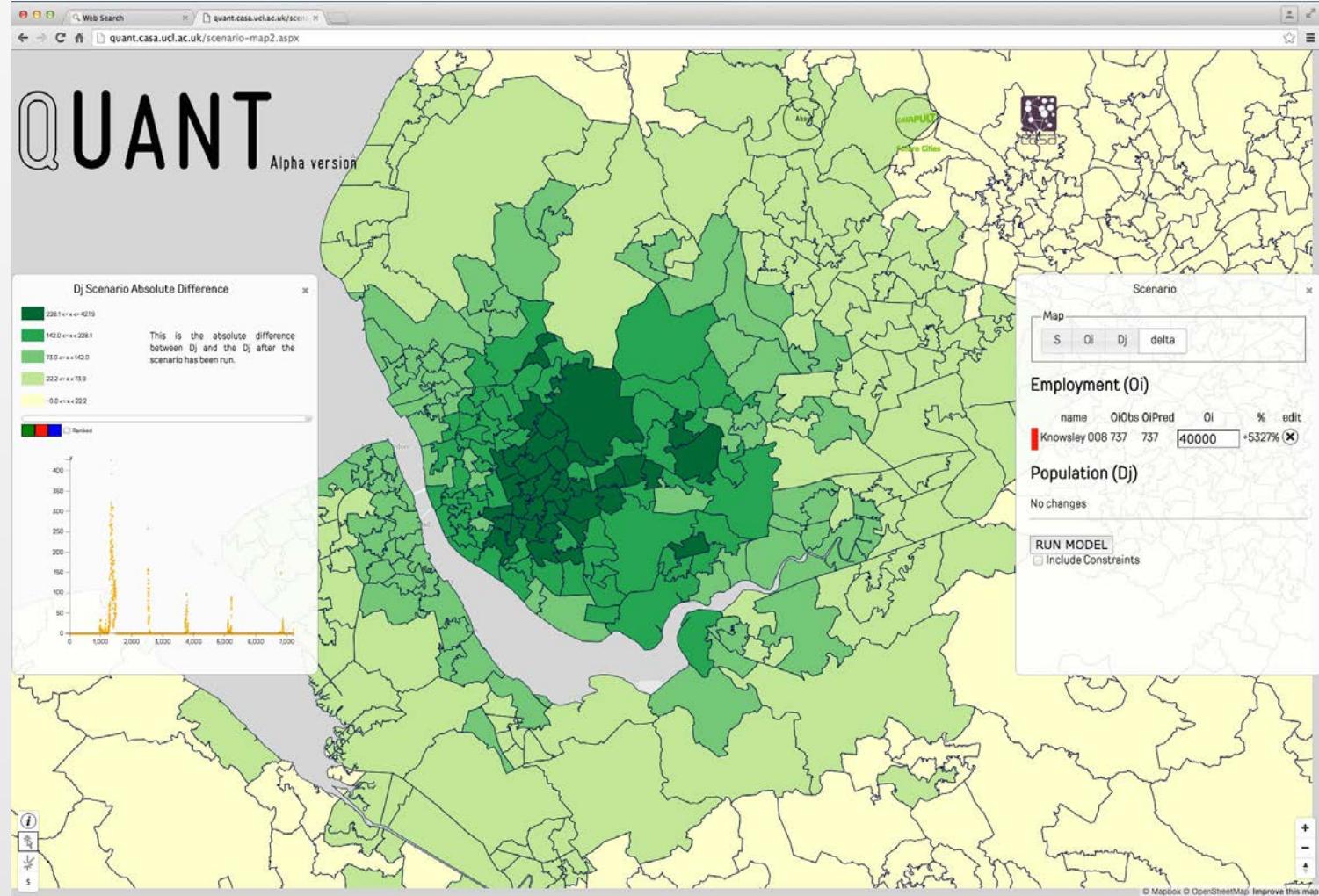


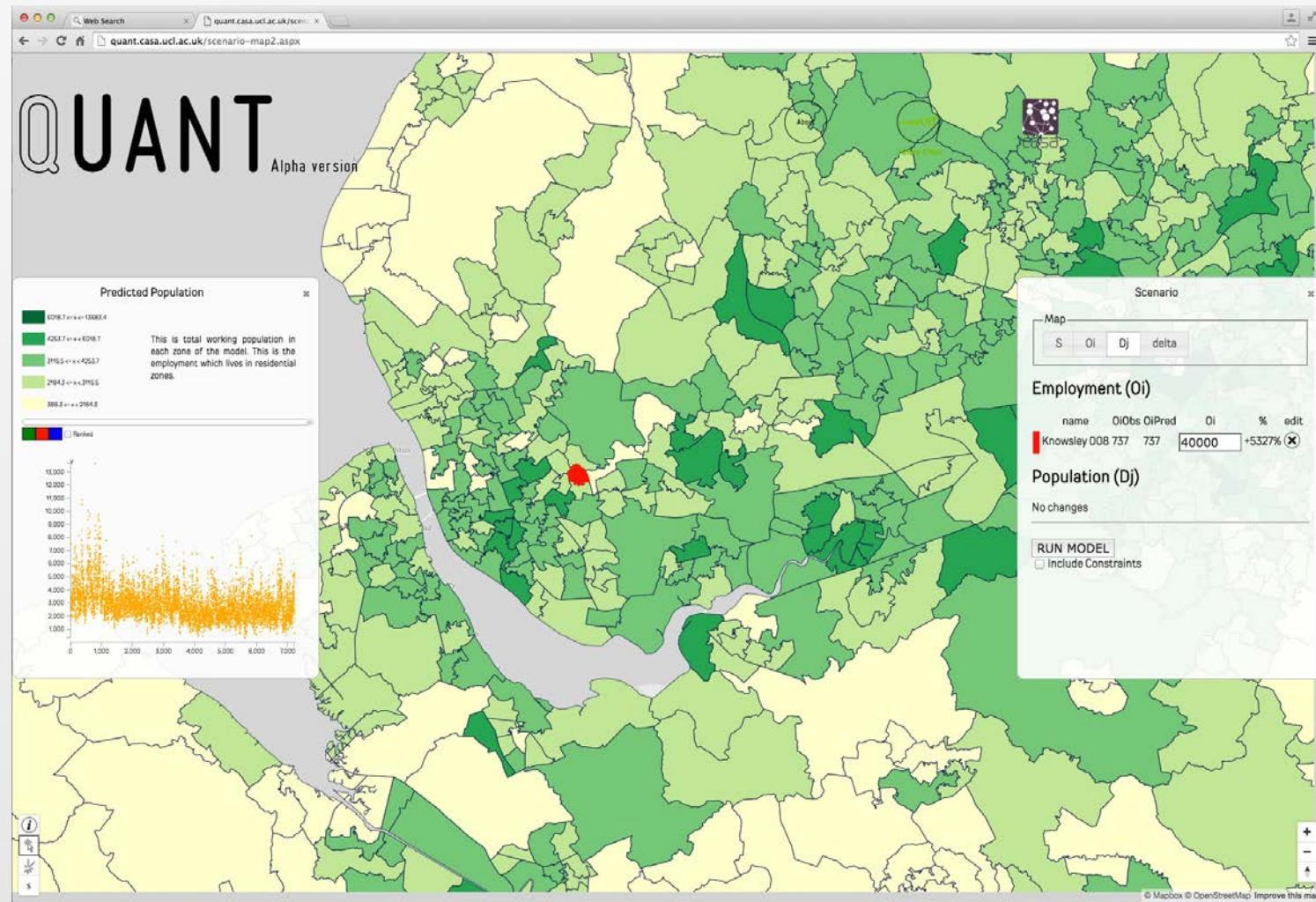


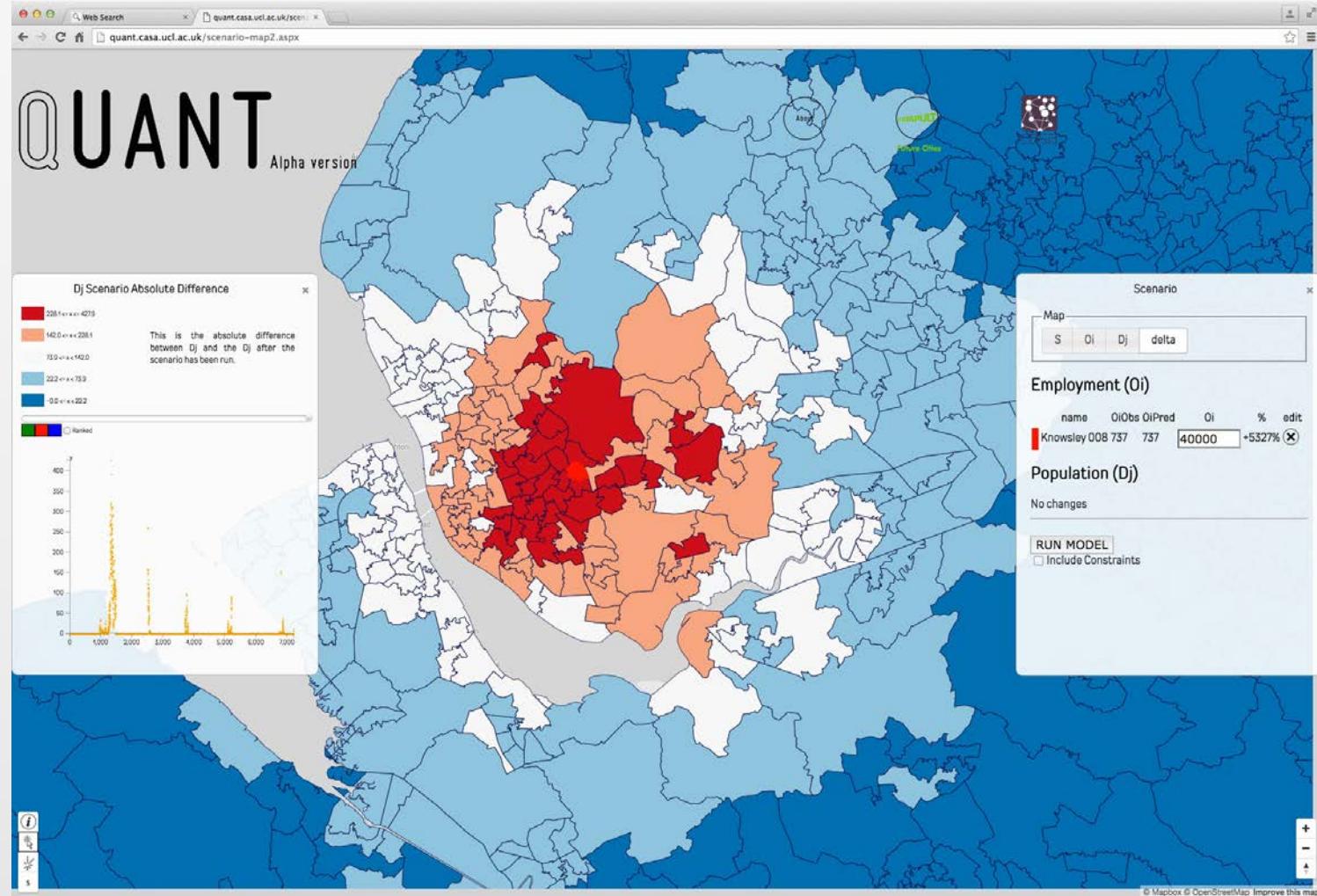








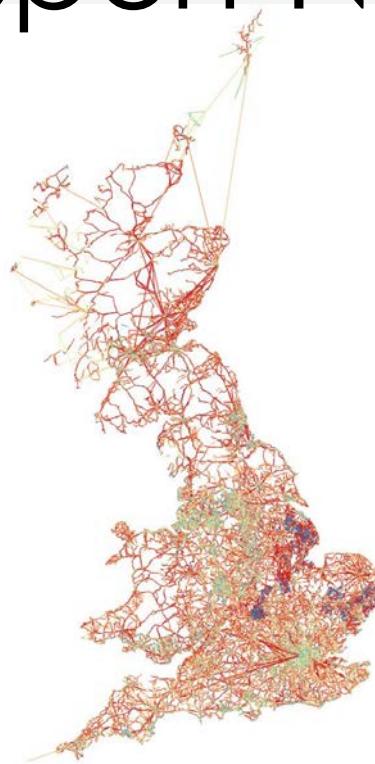




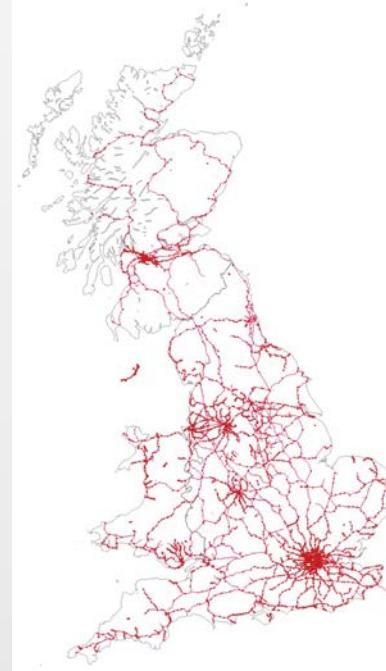
Transport Networks



Road, v=3.5M, e=8.4M



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



Rail, v=3165, e=10,269

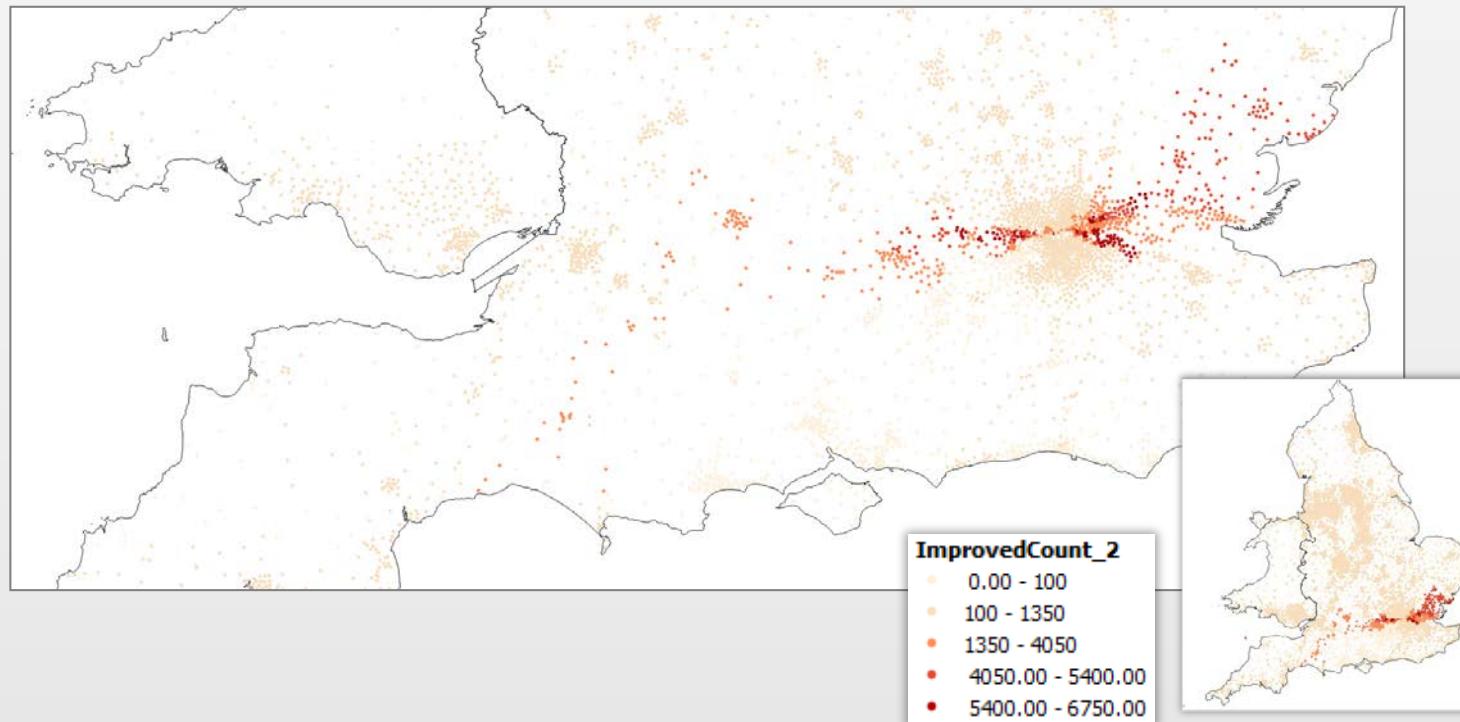
Crossrail

Reading, Heathrow, Shenfield, Abbey Wood



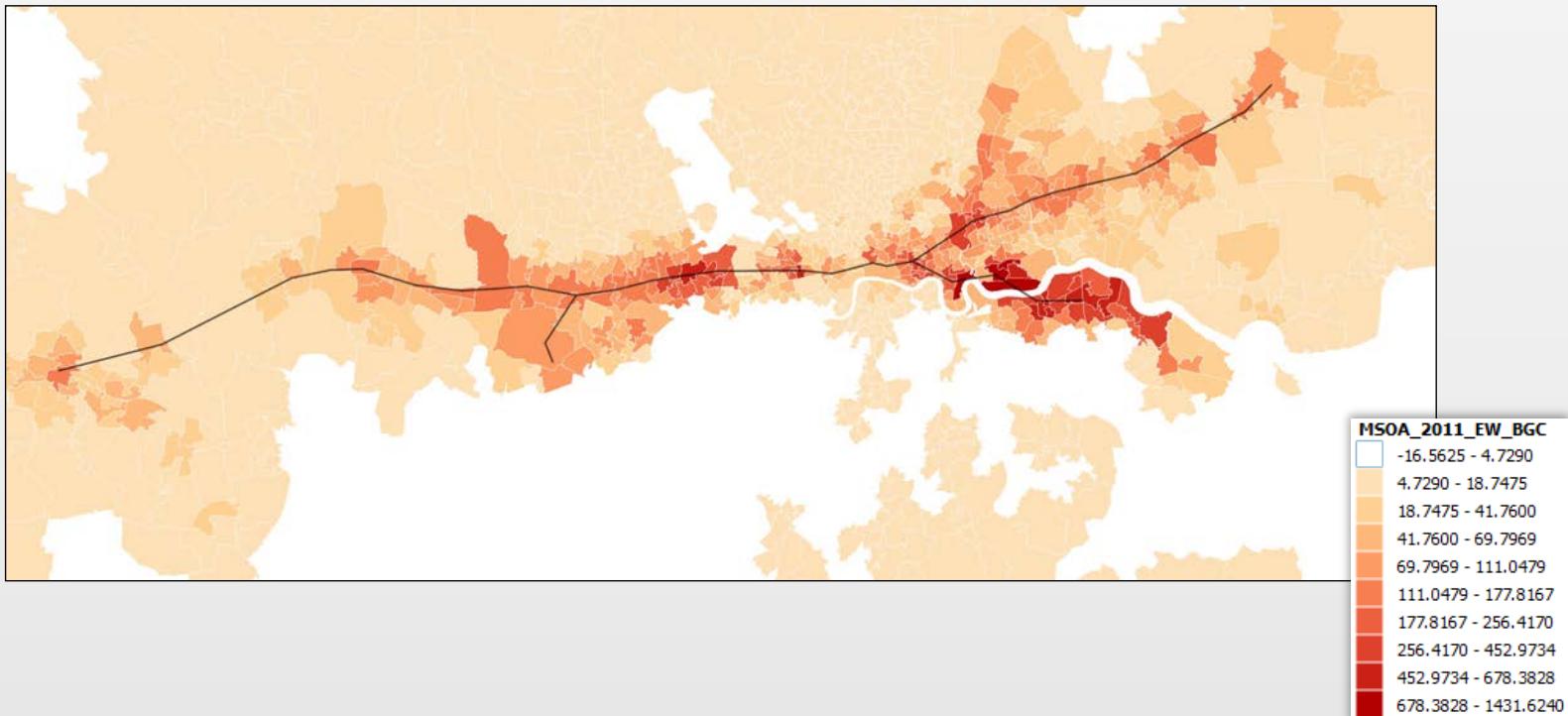
Crossrail

Number of Improved Journeys (ni)



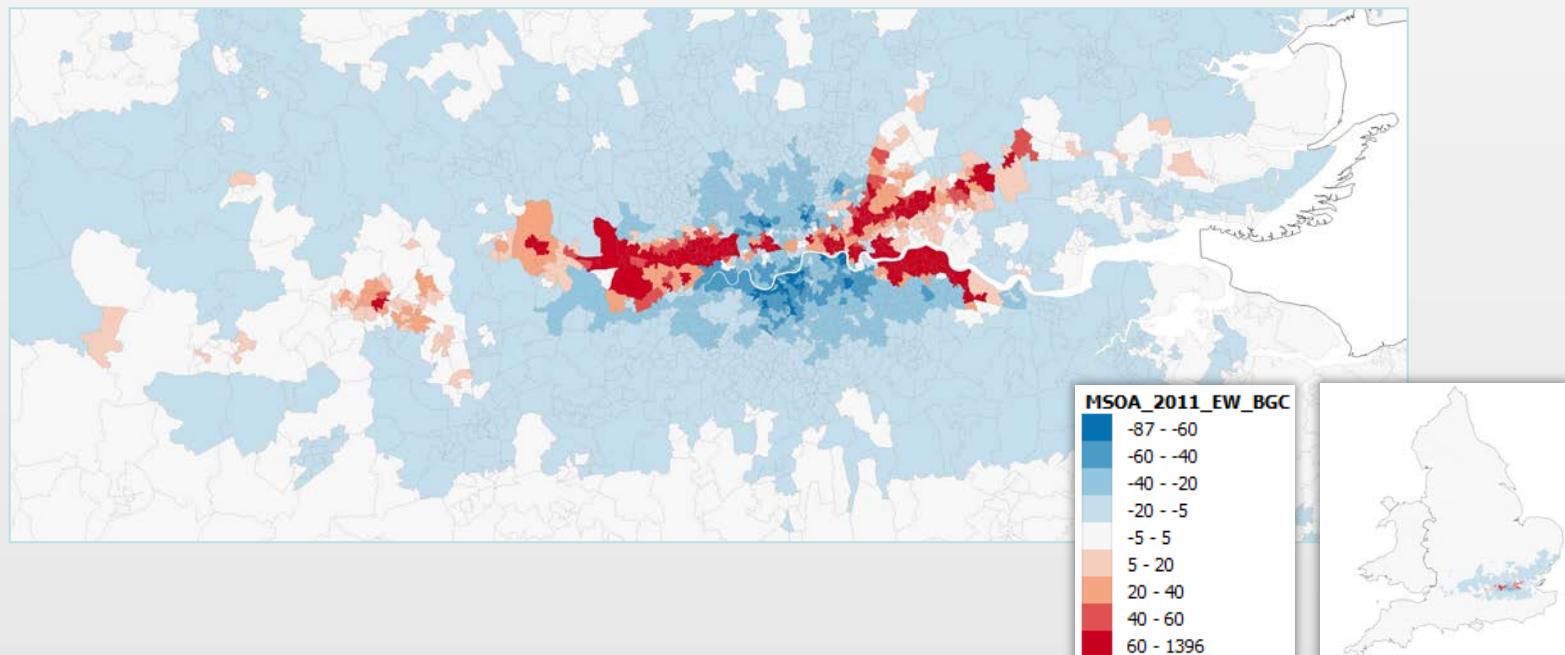
Crossrail

Population change (rail mode only)



Crossrail

Population Change (all modes)





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A central panel containing logos and names of collaboration partners. At the top right is the CATAPULT Future Cities logo. Below it is the UKCRIC logo. To the left of the UKCRIC logo are the Infrastructure and Projects Authority and National Infrastructure Commission logos, each featuring a crest. At the bottom are the UKCRIC and UKRI Science and Technology Facilities Council logos.

<https://www.turing.ac.uk/>



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The screenshot shows a web browser window for arXiv.org. The header includes the Cornell University logo, a search bar, and a note about Simons Foundation support. The main content area displays the article 'Building a Digital Twin for British Cities' under the category 'Physics > Physics and Society'. The article was submitted on 6 Dec 2023. It features a red banner with the arXiv logo and the Cornell University logo. The right sidebar provides access options like PDF download and a Creative Commons license link, along with the current browse context 'physics.soc-ph'.

Special issue article: Big data in the city

A new framework for very large-scale urban modelling

Michael Batty  and Richard Milton

University College London, UK

Urban Studies

Urban Studies
2021, Vol. 58(15) 3071–3094
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