Lectures on Urban Modelling January 2017

Integrated Urban Models

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http://www.spatialcomplexity.info/

Outline

- Modular Modelling: Coupled Spatial Interaction
- A Simple Example of Modularity: Lowry's Model
- DRAM-EMPAL Style Models
- Demand and Supply: Market Clearing
- Input-Output: The Echenique Models
- Integrated Large-Scale Model Structures
- Sketch for an Integrated Model
- Demonstrating an Aggregate Large Scale Model
- Very Rapid Prototyping of Aggregate Models

Modular Modelling: Coupled Spatial Interaction

So far we have just singled out a module for one kind of interaction – based on a variant of the gravity model - consider stringing these together as more than one kind of spatial interaction: Model 1 ⇨ Model 2 ⇨ Model 3 ⇨ .....

Classically we might model flows from home to work and home to shop but there are many more and in this sense, we can use these as building blocks for wider models. This is for next time too

What we will now do is illustrate how we might build such a structure taking a journey to work model from Employment to Population and then to Shopping which we structure as --

First we have the journey from work to home model as

$$T_{ij} = E_i \frac{F_j \exp(-\lambda c_{ij})}{\sum_j F_j \exp(-\lambda c_{ij})} \quad , \quad \sum_j T_{ij} = E_i$$

$$P_j = \alpha \sum_i T_{ij}$$

And then the demand from home to shop

$$S_{jm} = P_j \frac{W_m \exp(-\beta c_{jm})}{\sum_m W_m \exp(-\beta c_{jm})} \quad , \quad \sum_m S_{jm} = P_j$$

$$S_m = \sum_j S_{jm}$$

And there is a potential link back to employment from the retail sector

$$E_m = f(S_m)$$

A Simple Example of Modularity: Lowry's Model

Lowry's (1964) model of Pittsburgh was a model of this nature but it also incorporated in it – or rather its derivatives did more formally – a generative sequence of starting with only a portion of employment – basic – and then generating the non-basic that came from this. This non-basic set up demand for more non-basic and so on until all the non-basic employment was generated, and this sequence followed the classic multiplier effect that is central to input-output models.

A block diagram of the model follows

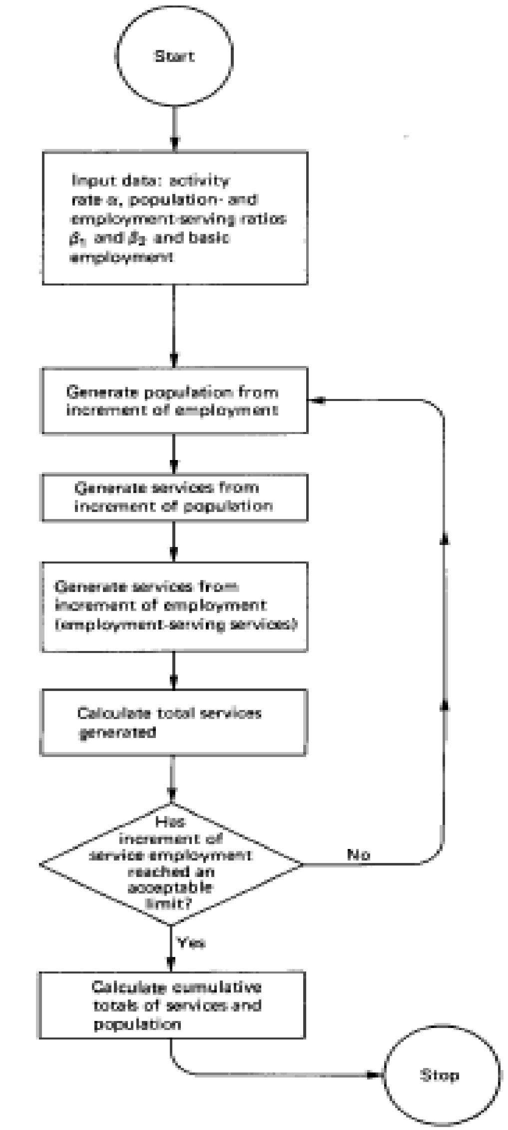


Fig. 2.1. The sequence of operations in generating population and services from basic employment.

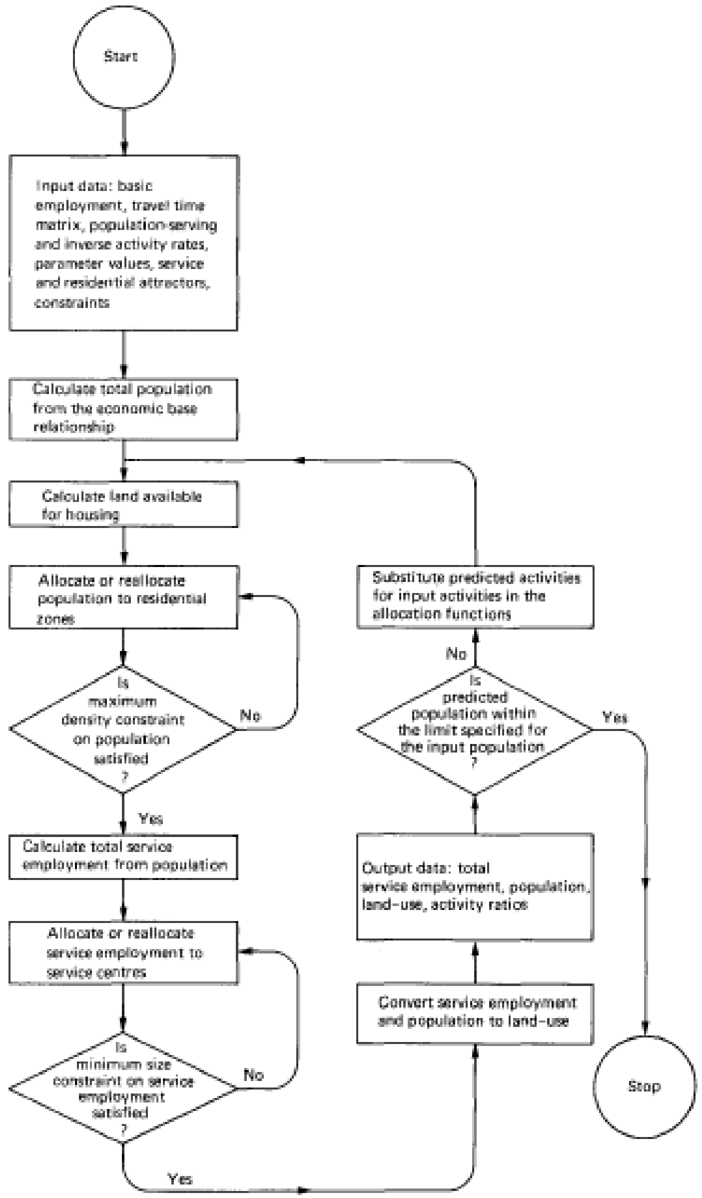


Fig. 3.2. Generalised flow chart of the Lowry model.

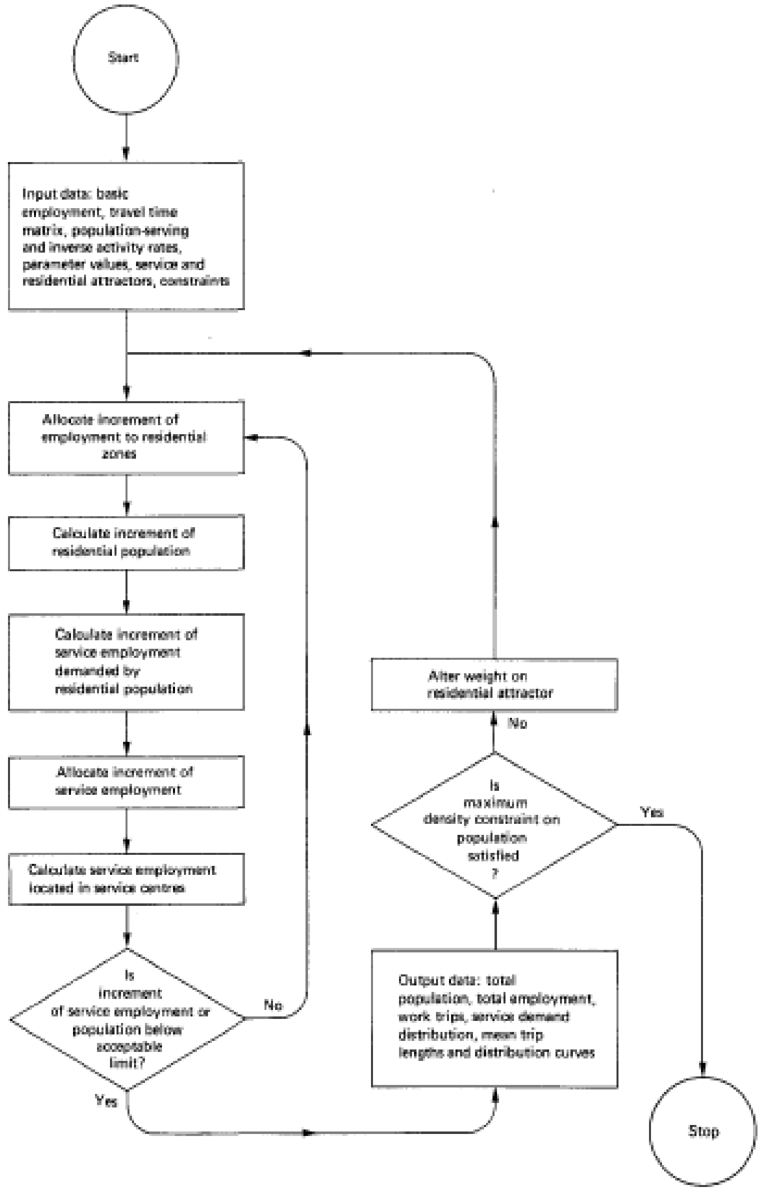


Fig. 3.3. Generalised flow chart of the Activity Allocation model.

DRAM-EMPAL Style Models

Essentially what we have here is the notion of simultaneous dependence – i.e. one activity generates another but that other activity generates the first one – what came first – the chicken or the egg?

Stephen Putman developed an integrated model to predict residential location DRAM and another to predict employment location EMPAL. In essence different models are used to do each – the employment model tends to be based on very different factors – it is a regression like model of key location factors not a flow model

Now some models take the transport component out and use accessibility, then interfacing with a transport model that is built externally

Demand and Supply: Market Clearing

So far most of these models have been articulated from the demand side – they are models of travel demand and locational demand – they say nothing about supply although we did introduce the notion that in simulating trips and assigning these to the network, we need to invoke supply.

When demand and supply are in balance, then the usual signal of this is the price that is charged. In one sense the DRAM EMPAL model configures residential location as demand and employment location as supply but most models tend to treat supply as being relatively fixed, given, non-modellable

However several models that couple more than one activity together treat supply as being balanced with demand, often starting with demand, seeing if demand is met, if not changing the basis of demand and so on until equilibrium is ascertained. Sometimes prices determines the signal of this balance. If demand is too high, price rises and demand falls until supply is met and vice versa. Often this is done simply to ensure demand is not greater than supply

Most urban models do not attempt to model supply for supply side modelling is much harder and less subject to generalisable behaviour

A strategy for ensuring balance is as follows for a model with two sectors – like the one we illustrated earlier

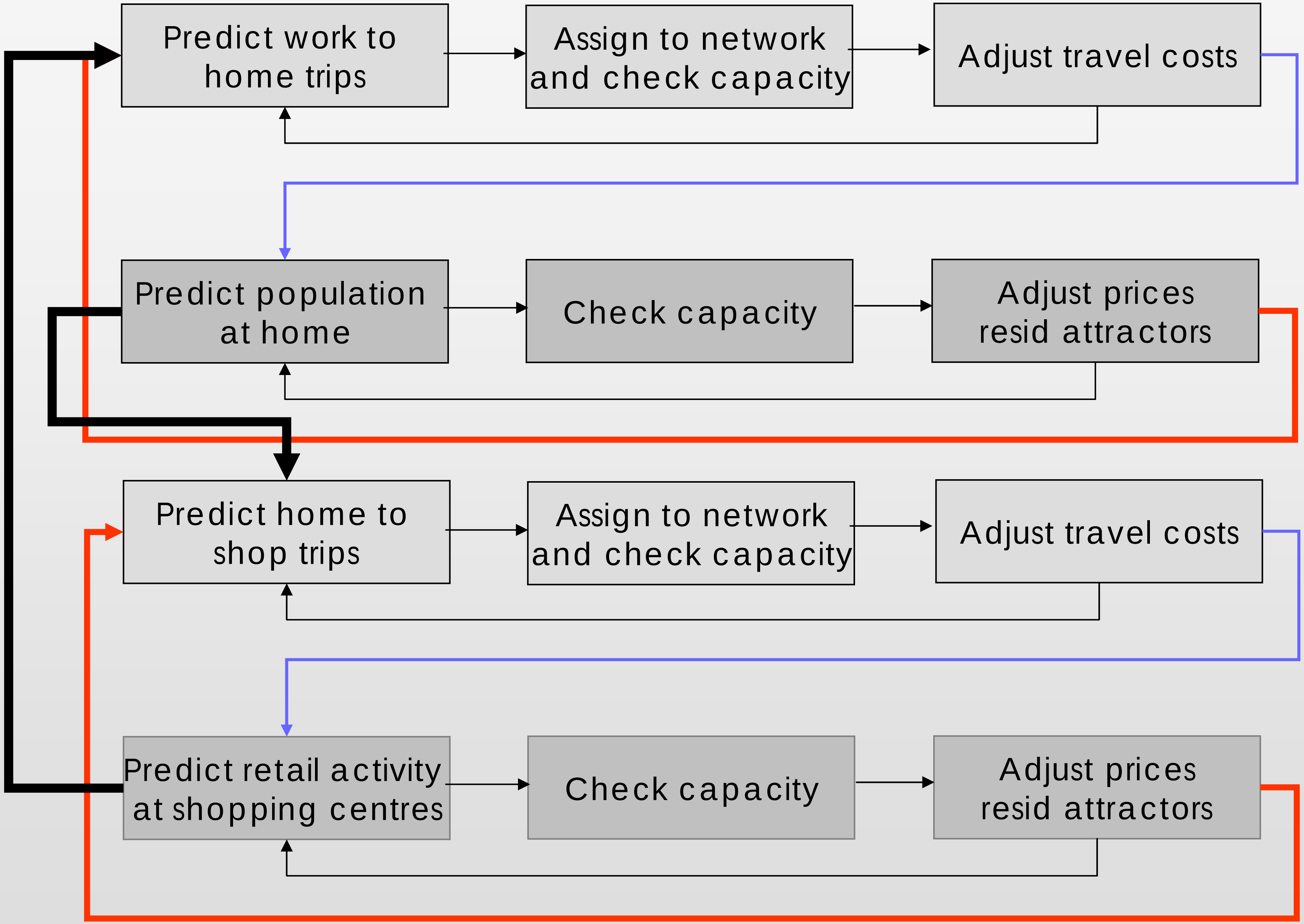
In the following slide, we have two submodels – first residential location and second retail location

In each submodel, we first have interaction (trip distribution) and then location.

The first loops in terms of interaction are for capacity constraints on supply, the second are for capacity constraints on location

The second set of red loops involve reiterating the interaction and location so that we can get balance within the entire submodel

The thick black loop in the middle couples the residential to the retail model, the thick black loop around the two models is used if retail predictions are to influence employment


Predict work to home trips
Assign to network and check capacity
Adjust travel costs
Predict population at home
Check capacity
Adjust prices resid attractors
Predict home to shop trips
Assign to network and check capacity
Adjust travel costs
Predict retail activity at shopping centres
Check capacity
Adjust prices resid attractors

The decision to nest what loop inside what other loop is a big issue that makes these models non-unique

If the supply side is modelled separately then the way this is incorporated further complicates the sequence of model operations.

In the large scale integrated models that we will deal with next, these are crucial issues

There is one further structural issue we will deal and this involves extending the models sectorally and the Echenique input-output formulation is a good example of this extension

Input-Output: The Echenique Models

So far we have only developed couplings between models that are added together in ordered sequences that string sectors together apart from reference last time to the Lowry model which organised this sequence around the basic-non-basic employment multiplier.

We can extend this to a series of linked causal multipliers between different sectors by extending this chain to an input-output model framework. In essence we define many different sectors involving households, labour, industries, services and so on and build the model so that there are consistent economic relations between each

Echenique's MEPLAN models are structured in this fashion. So too is the TRANUS model. We can introduce these as follows.

Essentially the system is divided into production and consumption based on activities m that are produced in zone I, X_i^m, and consumed as activities n in zone j, Y_j^n

These are organised as in an input output table but noting that they are spatially specific

$$X_i^m = \sum_j \sum_n T_{ij}^{mn}$$

$$Y_j^n = \sum_i \sum_m T_{ij}^{mn}$$

Here is the typical I-O table

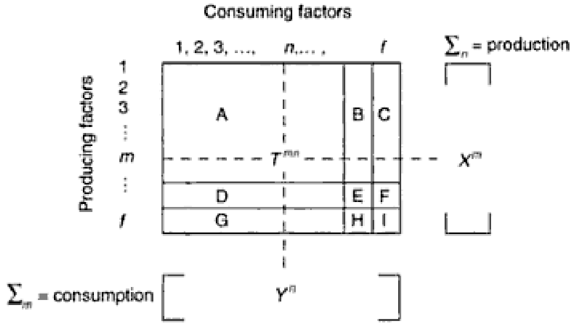


Figure 2. Transaction matrix *T*.

- Section A of the matrix T^{mn} represents the transactions between factors. This area is normally included in standard input–output models (Leontief, 1951). It represents the sales from sector m to sector n.
- Section B of the matrix T^{mn} represents the transactions between factor m and the household group n, in other words the consumption by the households of products or services m.
- Section C of the matrix T^{mn} represents the transactions between factors m to be exported to outside the area in consideration. Normally, both sections B and C are considered the final demand in standard input–output models that also includes investments and government consumption. It is described as the exogenous sector, that is to say, it is determined outside the model.
- Section D represents the sale of labor or other income received by socio-economic groups m from the factor n (e.g. dividends).
- Section E represents the sale of labor from socio-economic groups m to households in socio-economic groups n (e.g. domestic labor).
- Section F represents the sale of labor or other income received from the exogenous factor, such as pensions and other payments from government, etc.
- Section G represents the imports from outside the area and payments to the exogenous factor such as taxes to the government. In this sector, rental of property or land is sometimes included.
- Section H represents the payments by the households factor such as taxes, rental, etc.
- Section I represents payments by the exogenous factor to itself, such as imports for the government or for investments.

The flows are based on spatial interaction models of the form

$$T_{ij}^{mn} = Y_j^n \frac{\exp(-\beta^m c_{ij}^m)}{\sum_i \exp(-\beta^m c_{ij}^m)}$$

Where the generalised interaction costs also include other costs such as prices of good m at I

$$c_{ij}^m = p_i^m + t_{ij}^m + w_{ij}^m$$

The order in which these equations are solved and linked together is given in the following flow chart

Note that prices are determined from spatial interactions as

$$p_i^m = \frac{1}{\beta} \log \sum_i \exp(-\beta^m c_{ij}^m)$$

And then linked back to the prices of goods produced as

$$p_j^n = \sum_m a^{mn} p_j^m$$

$$a^{mn} = \frac{\sum_i \sum_j T_{ij}^{mn}}{\sum_j Y_j^n}$$

The precise details of how the model works are extremely hard to figure out from the papers but the following flow chart goes some way to showing how the various elements are configured.

This is a general point. In models that are coupled in this fashion – integrated, then it is often hard to figure out the precise ordering or the structure. I am just reading a PhD on the TRANUS model and this is a very complicated feature – what is solved first – the order.

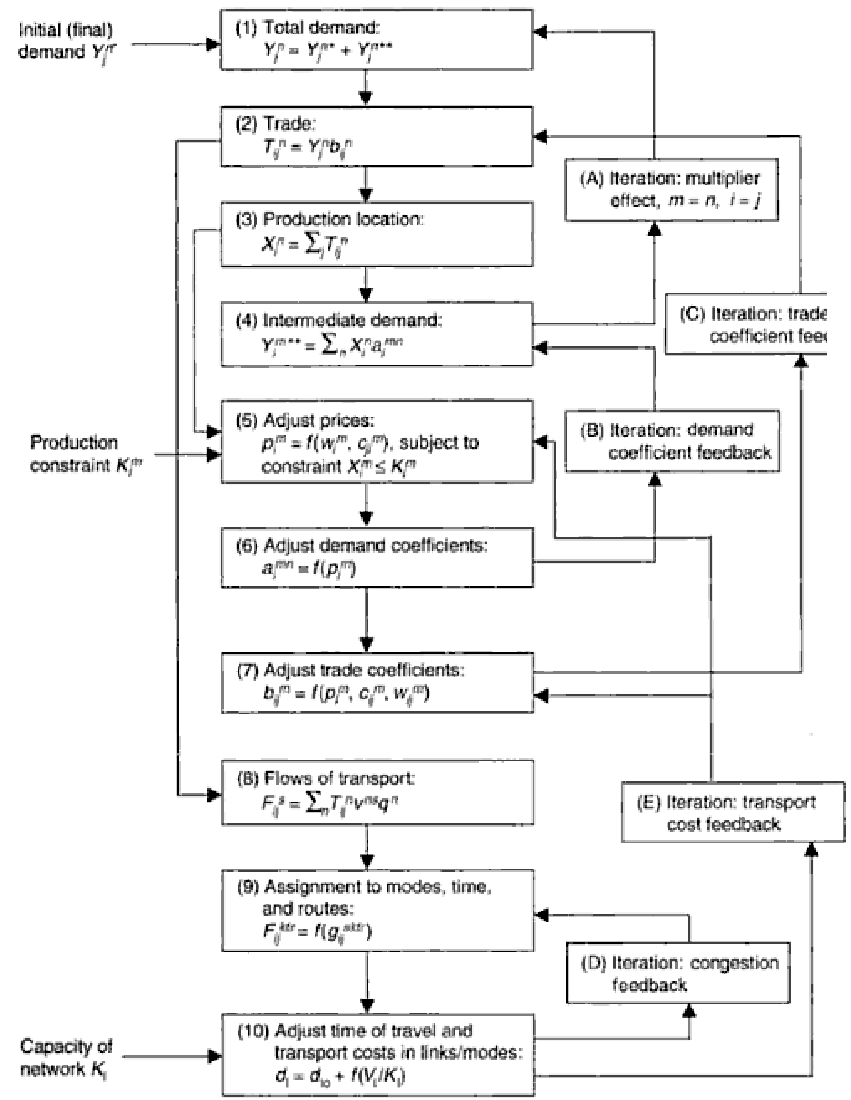
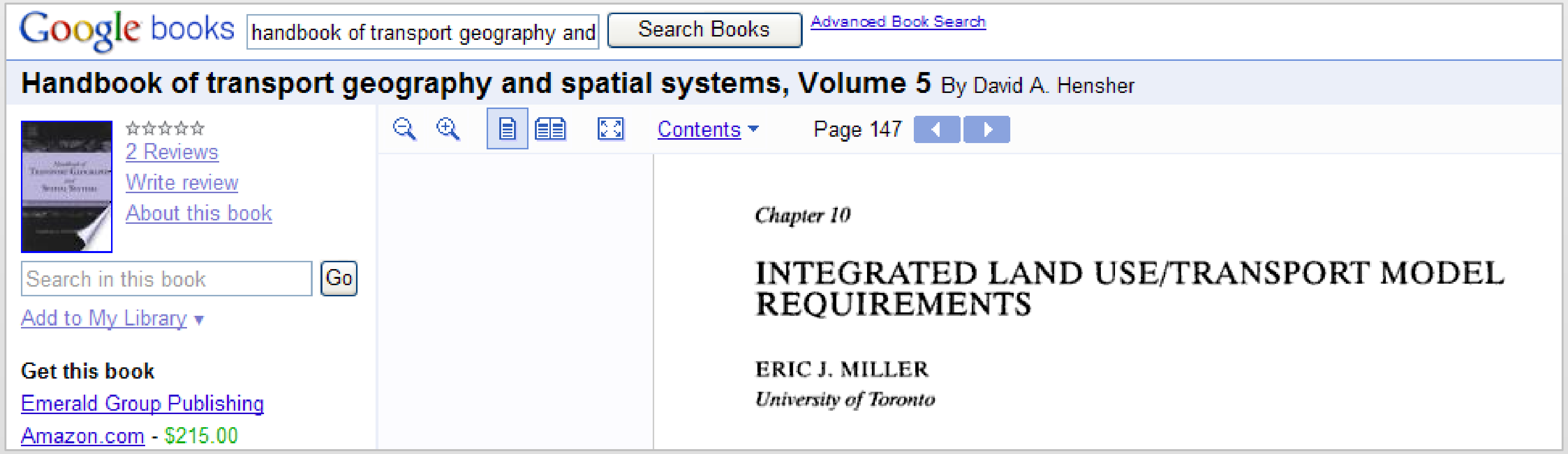


Figure 3. An integrated spatial system.

Integrated Large-Scale Model Structures

I will simply point you in the right directions here – the Handbook I referred you to in the last lecture contains several very good papers on these issues and I will briefly present some notes from Miller's article



Here is a summary from his article of the key structure of such models and also their requirements

148 *E.J. Miller*

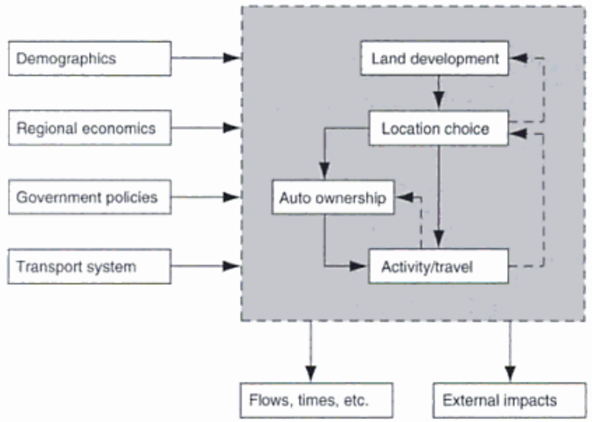


Figure 1. Integrated urban modeling system framework.

Box 1
Integrated urban model design issues

Physical system representation
- Time
- Space (land)
- Building stock
- Transportation networks
- Services

Representation of processes
- Land development
- Location choices
- Job market
- Demographics
- Regional economics
- Automobile holdings
- Activity/travel demand
- Network performance

Representation of decision-makers
- Persons
- Households
- Private firms
- Public authorities

"Generic issues"
- Level of aggregation/disaggregation
- Endogenous versus exogenous treatment
- Level of "process type"
- Model specification

Implementation issues
- Data requirements
- Computational requirements
- Technical support requirements

Box 2
Model evaluation criteria

Credibility
- Theoretical soundness
- Policy sensitivity
- Precision (spatially, temporally)
- Validation

Feasibility
- Computational requirements
- Data requirements
- Technical support requirements
- Cost

Usability
- Ease of input preparation
- Model run time
- Output/presentation capabilities
- Portability/transferability
- Flexibility/adaptability

Table 1. General facts

Software	Developer	Operational history	Platform	Commercial availability	Support
ITLUP	S. H. Putman	Developed over the last 25 years; operationally applied in many US cities plus selected overseas (40 plus calibrations)	Originated in FORTRAN for mainframe/work-station. PC version (METROPILUS) in ArcView shell, which provides linkage to ArcView GIS (Windows compatible)	Yes	Consulting firm, with commercial documentation and technical support (user's manual, newsletter, user group)
MEPLAN	M. Echenique	Much shared history over 25-year development. Operational applications throughout the world, including the USA (Sacramento for both; Washington State for MEPLAN; Oregon State and Baltimore for TRANUS)	MEPLAN originated in FORTRAN for mainframe; now PC based	Yes	Consulting firm, with commercial documentation and technical support (user's manual, newsletter)
TRANUS	T. de la Barra		TRANUS developed directly for PC (Windows orientation)	Yes	Consulting firm, with commercial documentation and technical support (user's manual)
MUSSA	F. Martinez	Operational in Santiago, Chile. Developed over last 8–10 years	PC based; runs under Windows. Interfaces with a relational database management system (Access). GUI and GIS	Yes	University-based research team in collaboration with the Government of Chile
NYMTC-LUM	A. Anas	Currently being implemented in New York City. Based upon previous models (CATLAS, CPHMM, NYSIM) developed in Chicago and New York over the last 20 years	PC or workstation. FORTRAN program	Yes	Alex Anas & Associates (a small firm). Limited documentation
UrbanSim	P. Waddell	Currently being implemented in Honolulu, Eugene/Springfield and Salt Lake City. Historical validation performed in Oregon	Platform independent, written in Java. Viewer currently implemented in MapObjects GIS on Windows 95/NT	Yes; public domain via website (www.urbansim.org)	University of Washington. Limited documentation currently. Reference manual, user guide, software available at website (www.urbansim.org)

To cite this Article Hunt, J. D. , Kriger, D. S. andMiller, E. J.(2005) 'Current operational urban land-use-transport modelling frameworks: A review', Transport Reviews, 25: 3, 329 — 376

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URL: http://dx.doi.org/10.1080/0144164052000336470

Sketch for an Integrated Model

I am very quickly going to sketch an integrated model which builds on the ideas so far – I will not disaggregate the model into m employment types and n housing types but we can assume that this is a complicating feature that simply makes the presentation trickier – so we will simply deal with the aggregate version

The model has three sectors – employment, retailing and residential location with a link from retailing into part employment. Three different models are built for each sector – spatial interaction for residential and retailing and a linear model of land development for employment

We begin with the residential, then retail sector, then trips capacities, and finally employment

$$T_{ij}^{k} = E_i \frac{R_j \exp(-\lambda^k c_{ij}^k)}{\sum_{jk} \exp(-\lambda^k c_{ij}^k)}$$

$$P_j = \sum_{ik} T_{ij}^k$$

Residential location

$$if\ P_j > P_j^{\max} \rightarrow R_j^* = R_j \frac{P_j}{P_j^{\max}}$$

$$S_{jz}^{k} = P_j \frac{W_z \exp(-\lambda^k c_{jz}^k)}{\sum_{zk} \exp(-\lambda^k c_{jz}^k)}$$

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Retail location

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Capacitated Transport Constraints

$$E_i = X_i + \phi S_i$$

$$X_i = X \frac{\sum_q \alpha_q x_{qi}}{\sum_q \sum_i \alpha_q x_{qi}}$$

Employment location

$$E_i^* = X_i + \phi S_i$$

In the next slides, we show the loops which need to be invoked to balance demand and supply and to couple the submodels

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Employment location

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Here are all the loops

Demonstrating an Aggregate Large Scale Model

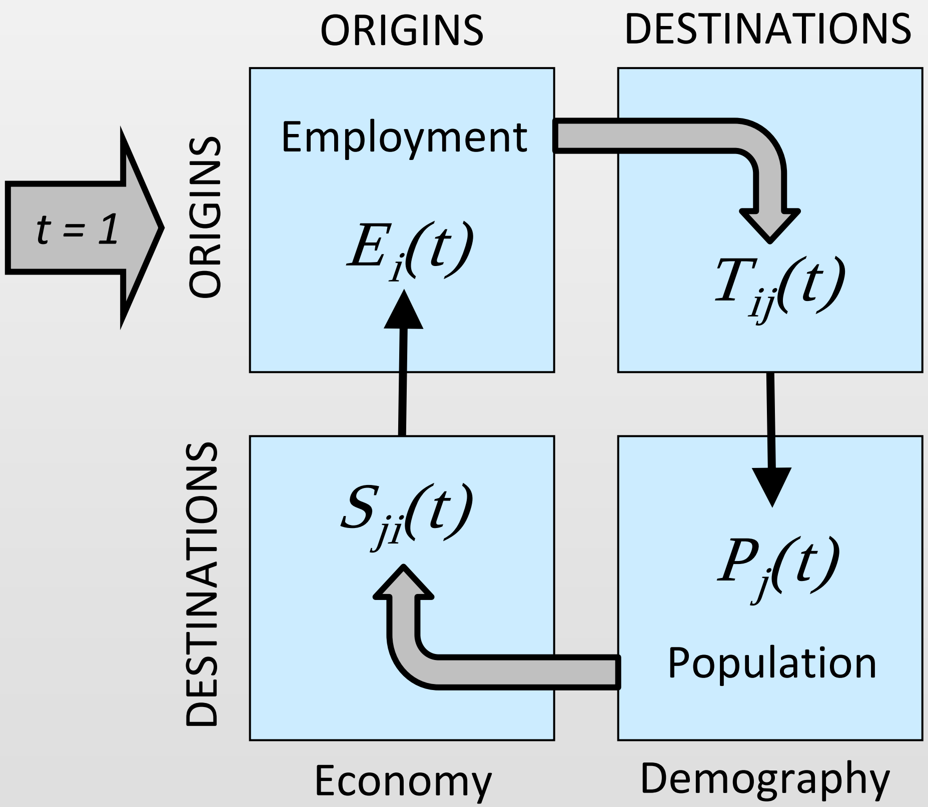
We have broadened our residential location model for London to Greater London and the outer metropolitan area and we will demonstrate this in a moment

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 – this is quite impossible in London as the market hardly follows any known theory

We simply use transport costs, wages and prices to determine residential location

Let me give you a quick summary of its structure:



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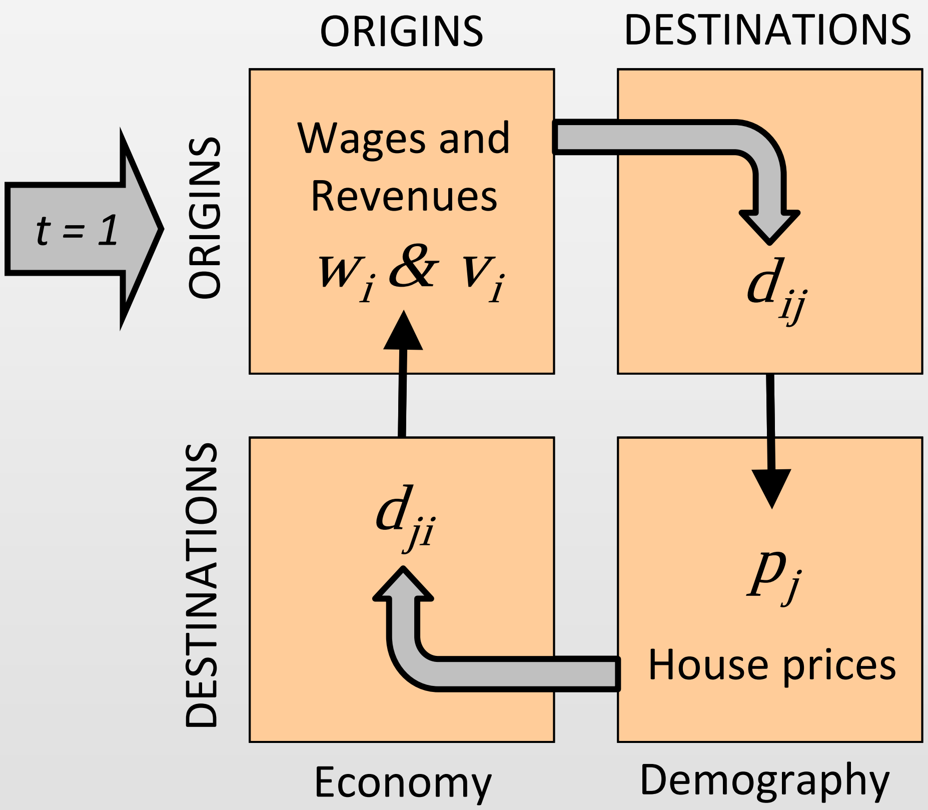
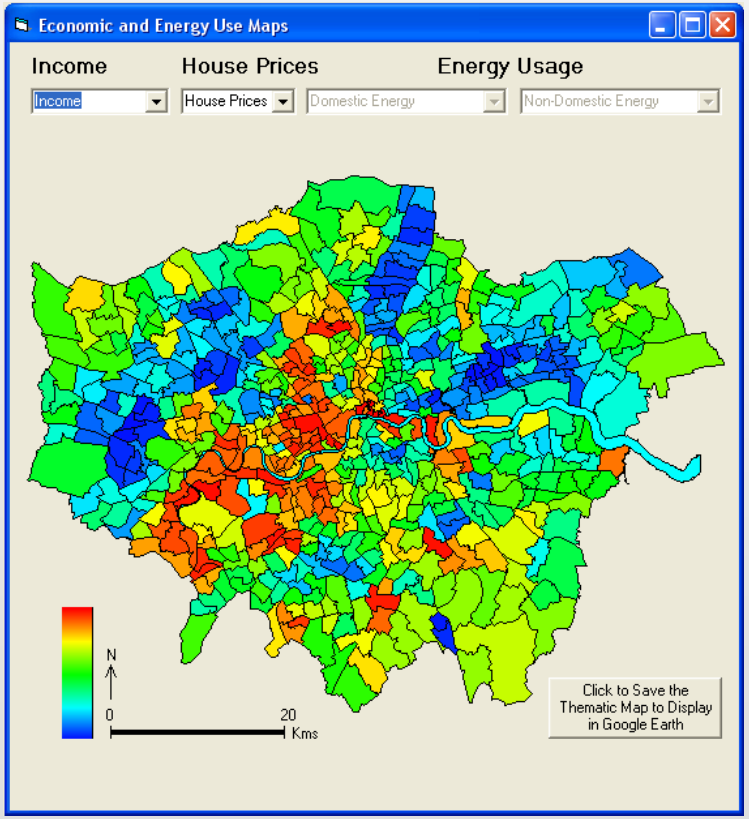
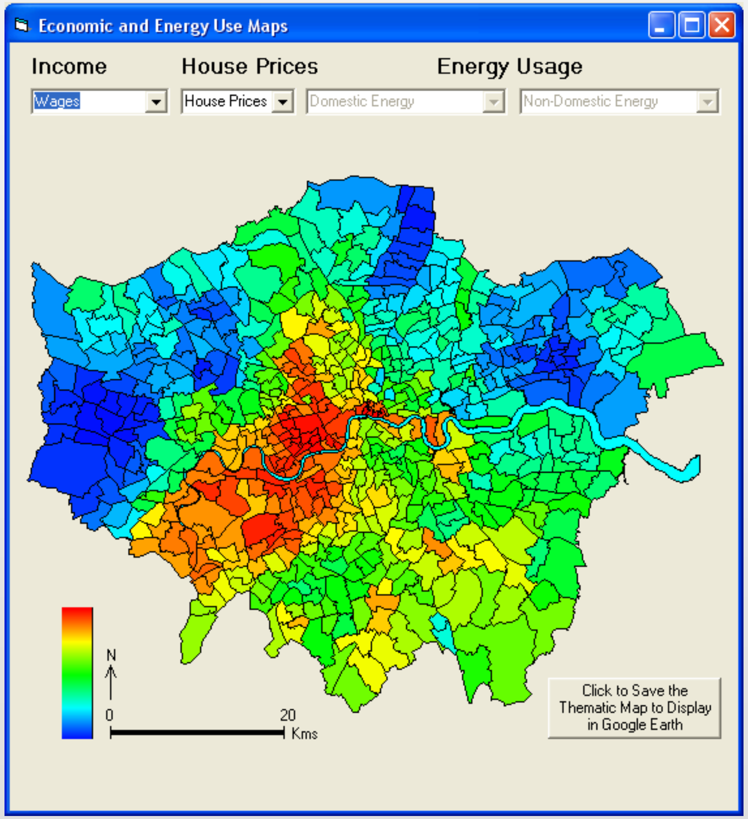


Other flows, than people or money, materials and information ?

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





And then we put wages, prices and transport costs together in the interaction model as follows with travel as a difference or variance σ^2 between these two sets of costs. Then, the system must satisfy the constraint

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

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

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

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

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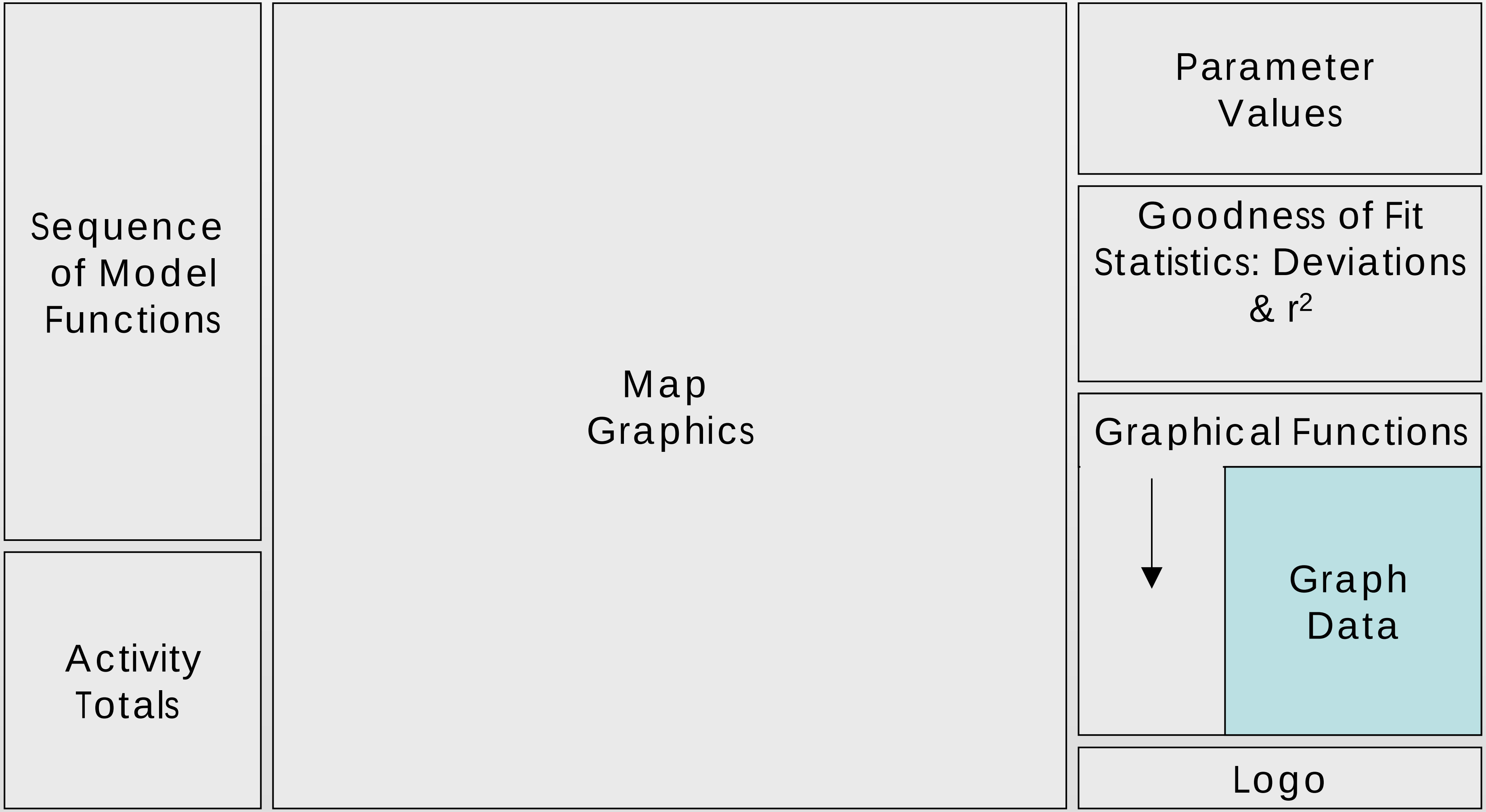
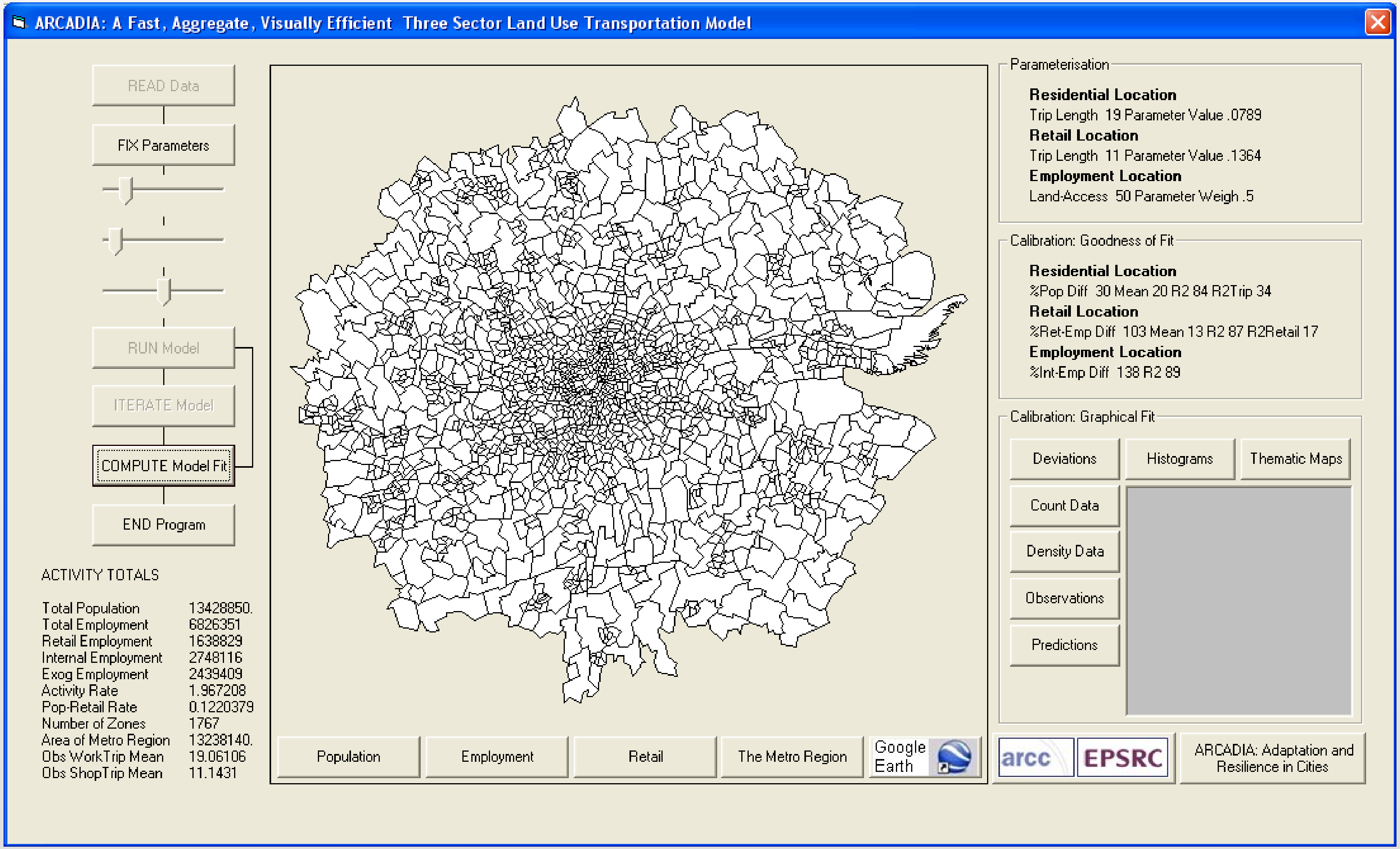
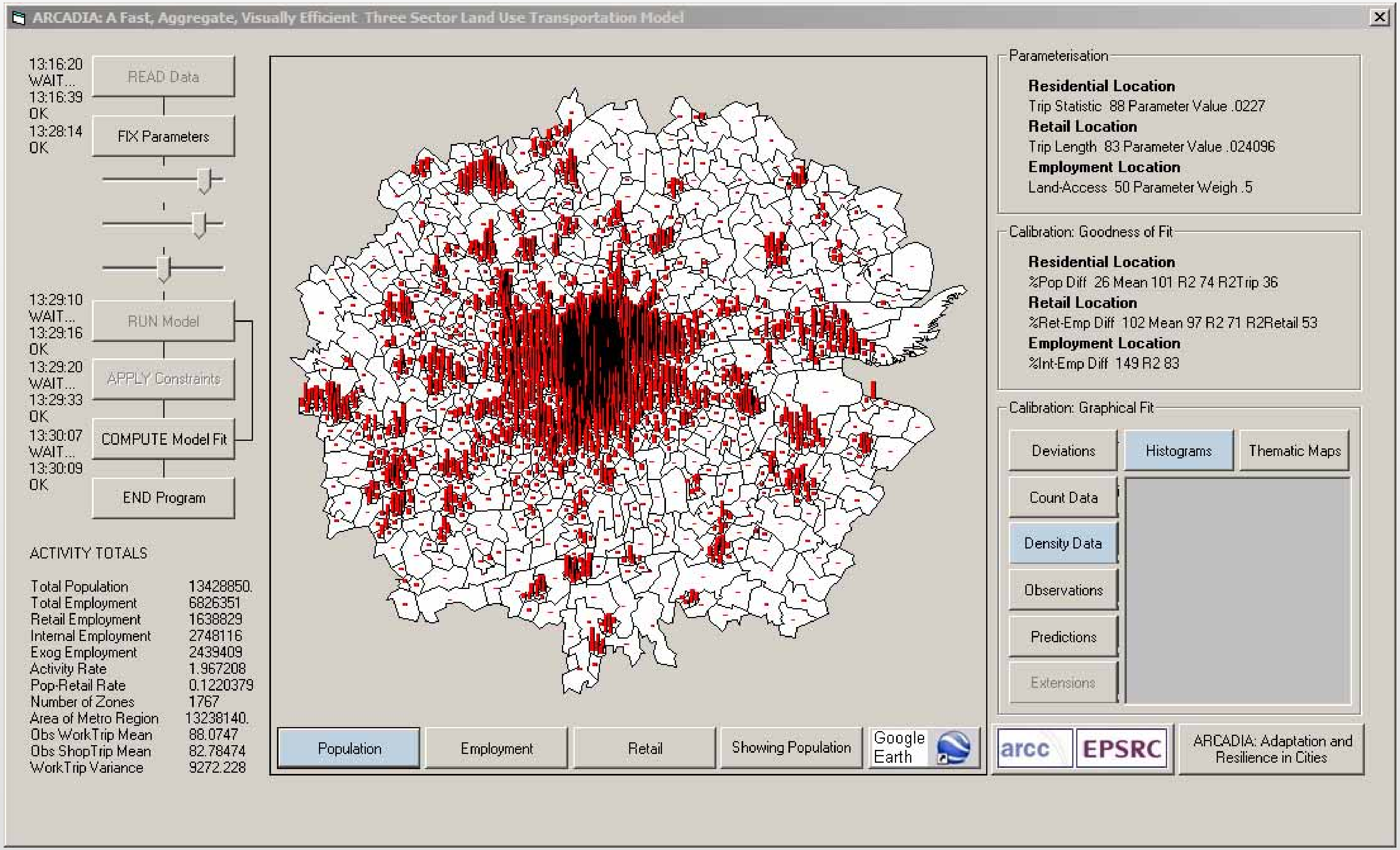
Visually-Driven Urban Simulation: exploring fast and slow change in residential location

Michael Batty

This is the order in which the operations take place



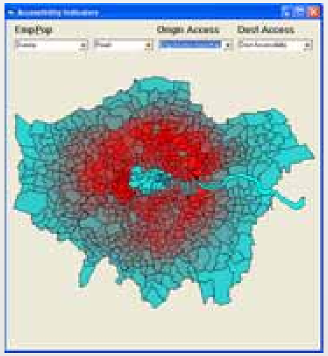

ARCADIA: A Fast, Aggregate, Visually Efficient Three Sector Land Use Transportation Model
READ Data
FIX Parameters
RUN Model
ITERATE Model
COMPUTE Model Fit
END Program
ACTIVITY TOTALS
Total Population 13428850.
Total Employment 6826351
Retail Employment 1638829
Internal Employment 2748116
Exog Employment 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

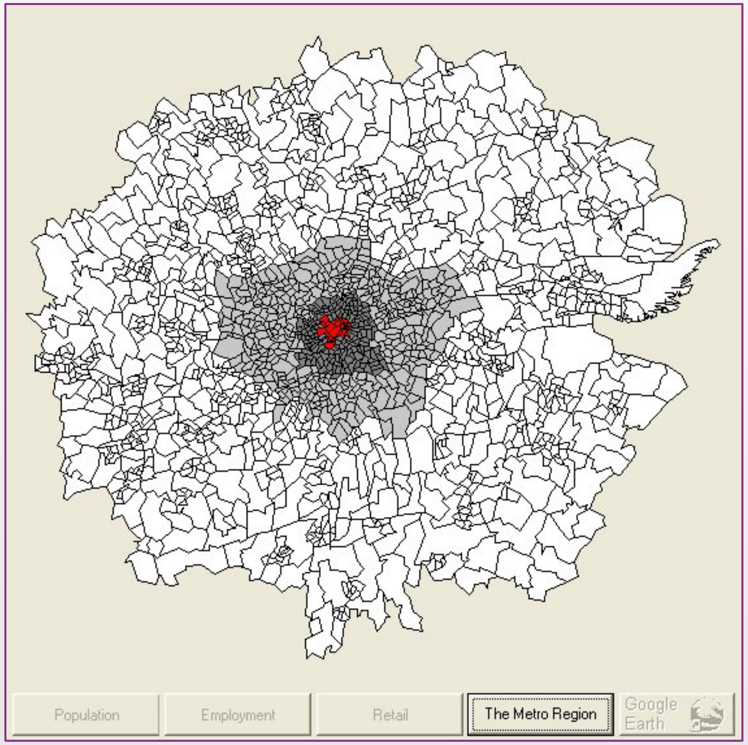


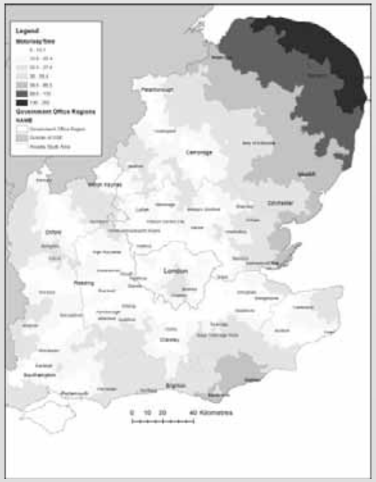
I will run the model as it works very quickly on the desktop


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


Employment
Population
Work Trips


Emp/Pop
Origin Access
Dest Access


Population
Employment
Retail
The Metro Region
Google Earth

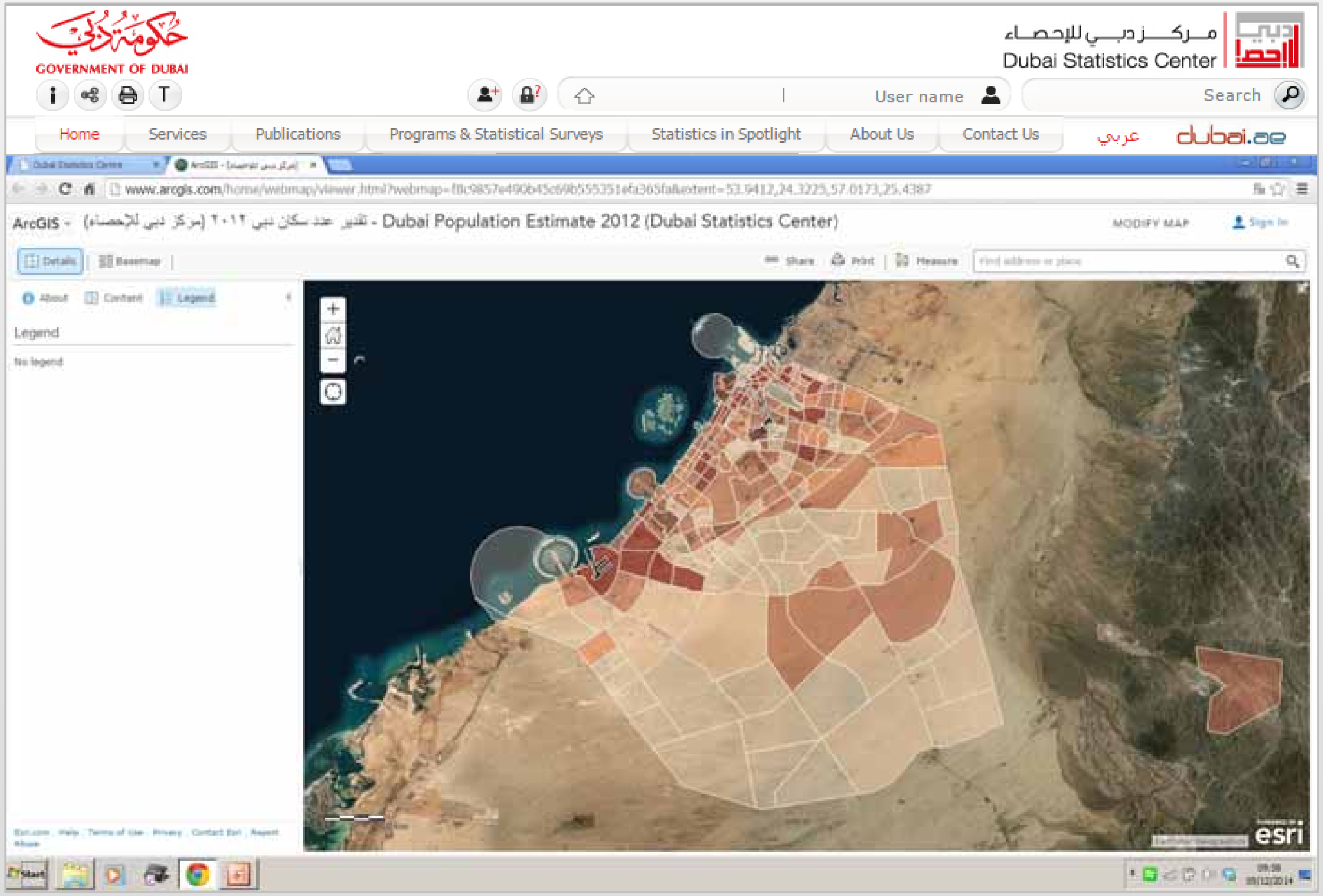



LONDON

Applications

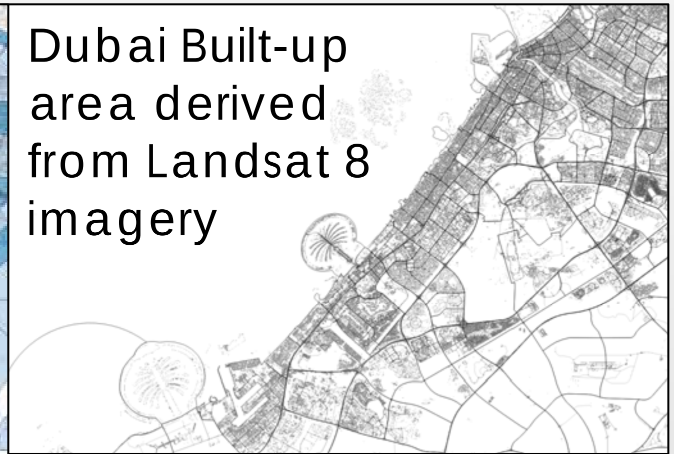
Very Rapid Prototyping of Aggregate Models

A New Retail Centre in Dubai

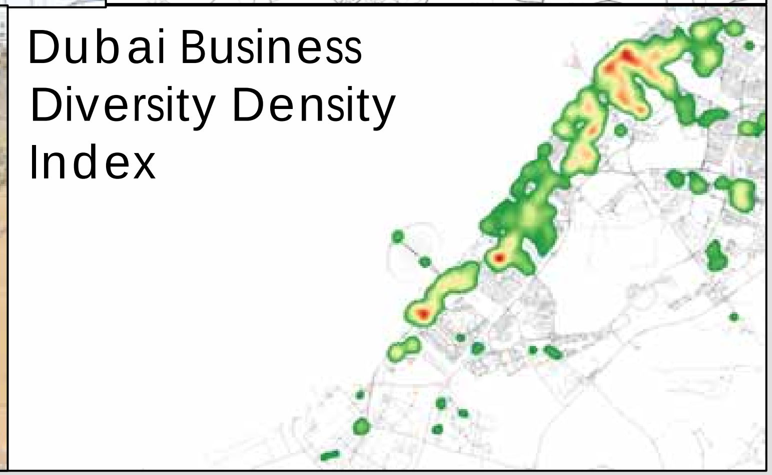


Where did we get the data – in a data poor environment?

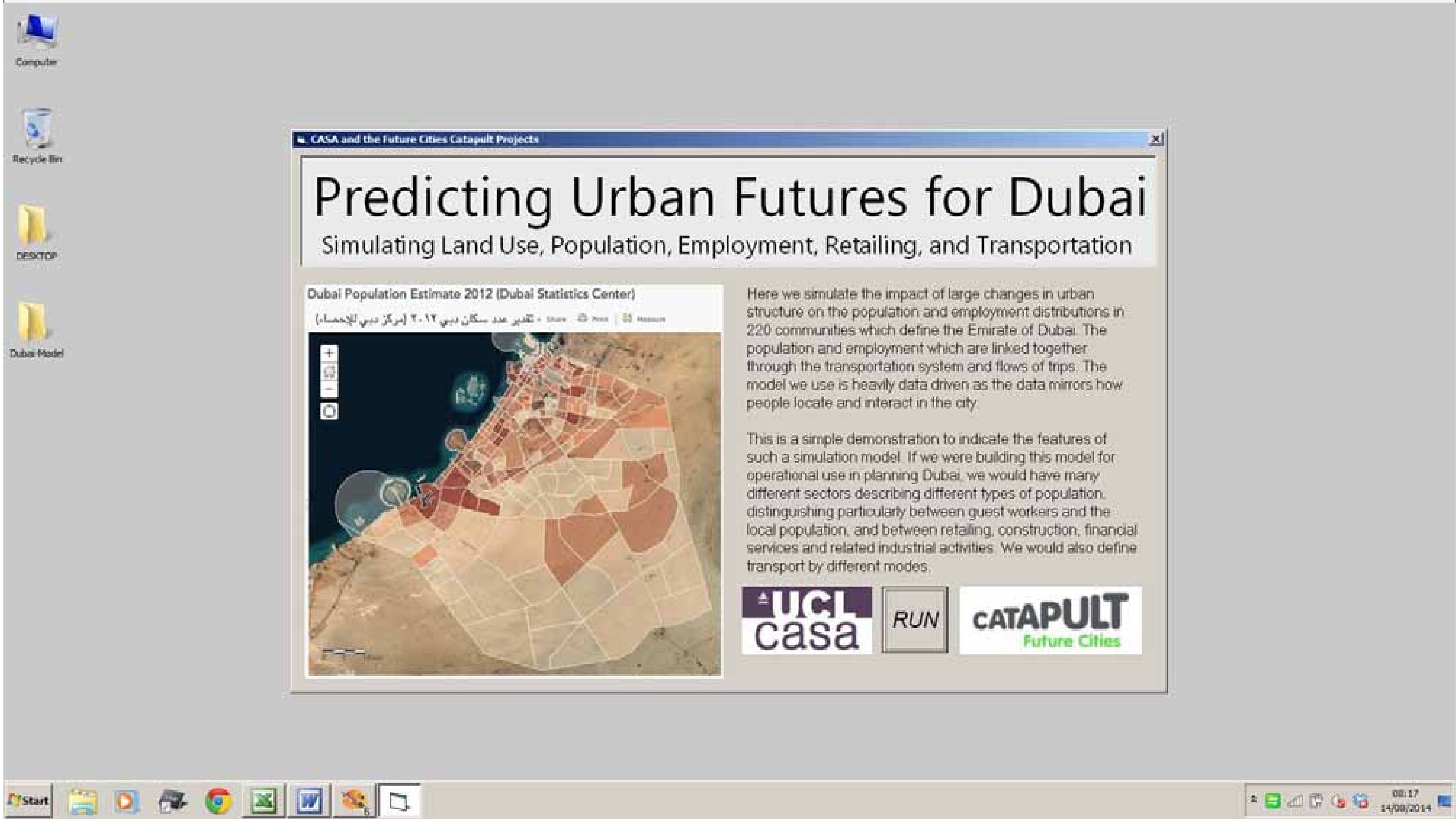
Dubai Business Density derived from Google Places API



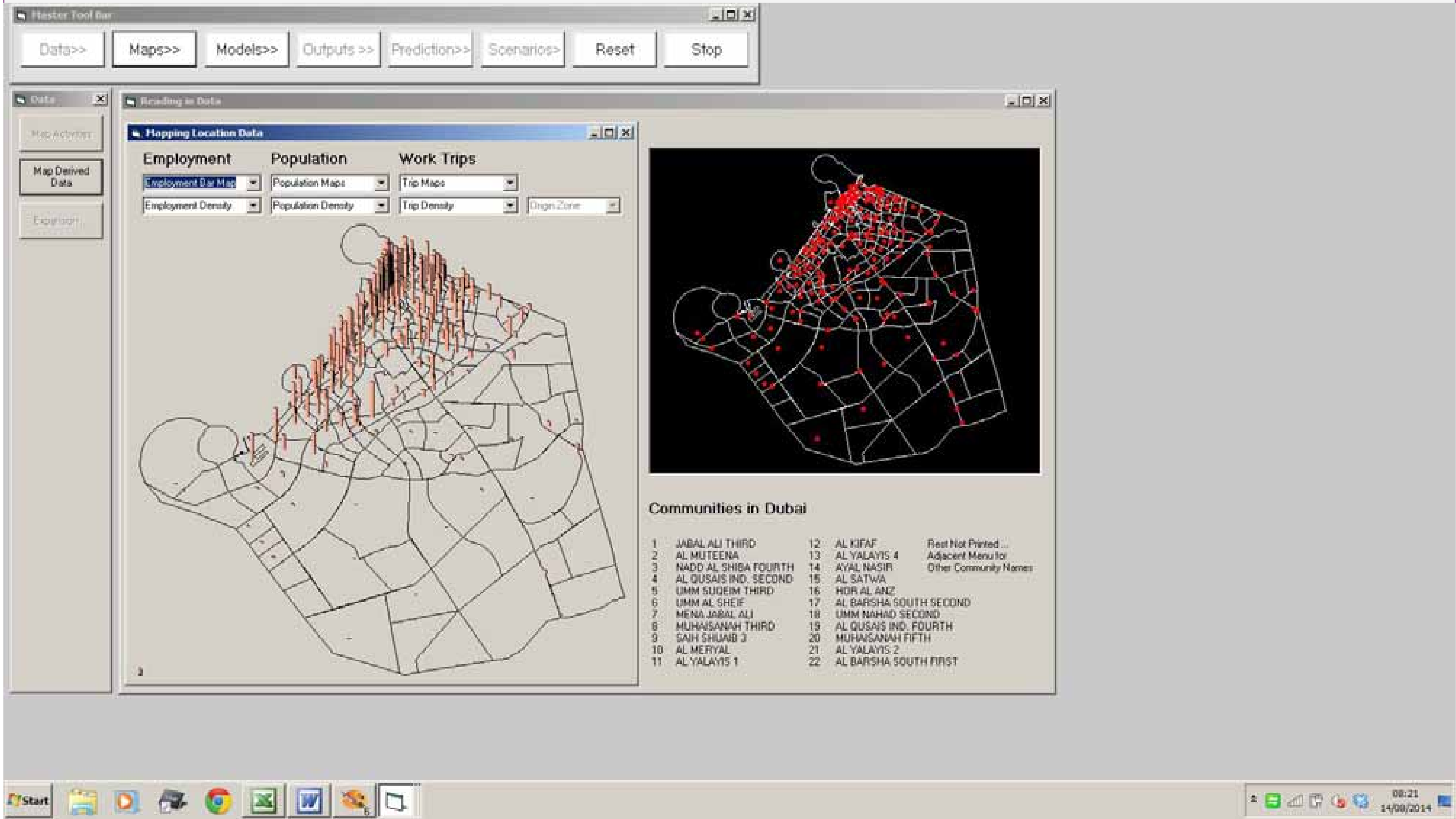
Dubai Built-up area derived from Landsat 8 imagery



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)
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
Start
08:17
14/08/2014


Data>>
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Stop
Map Derived Data
Mapping Location Data
Employment
Population
Work Trips
Employment Bar Map
Population Maps
Trip Maps
Employment Density
Population Density
Trip Density
Origin Zone
Communities in Dubai
1 JABAL ALI THIRD
2 AL MUTEENA
3 NADD AL SHIBA FOURTH
4 AL QUSAIS IND. SECOND
5 UMM SUQEIM THIRD
6 UMM AL SHEIF
7 MENA JABAL ALI
8 MUHAISANAH THIRD
9 SAIH SHUAIB 3
10 AL MERYAL
11 AL YALAYIS 1
12 AL KIFAF
13 AL YALAYIS 4
14 AYAL NASIR
15 AL SATWA
16 HOR AL ANZ
17 AL BARSHA SOUTH SECOND
18 UMM NAHAD SECOND
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20 MUHAISANAH FIFTH
21 AL YALAYIS 2
22 AL BARSHA SOUTH FIRST
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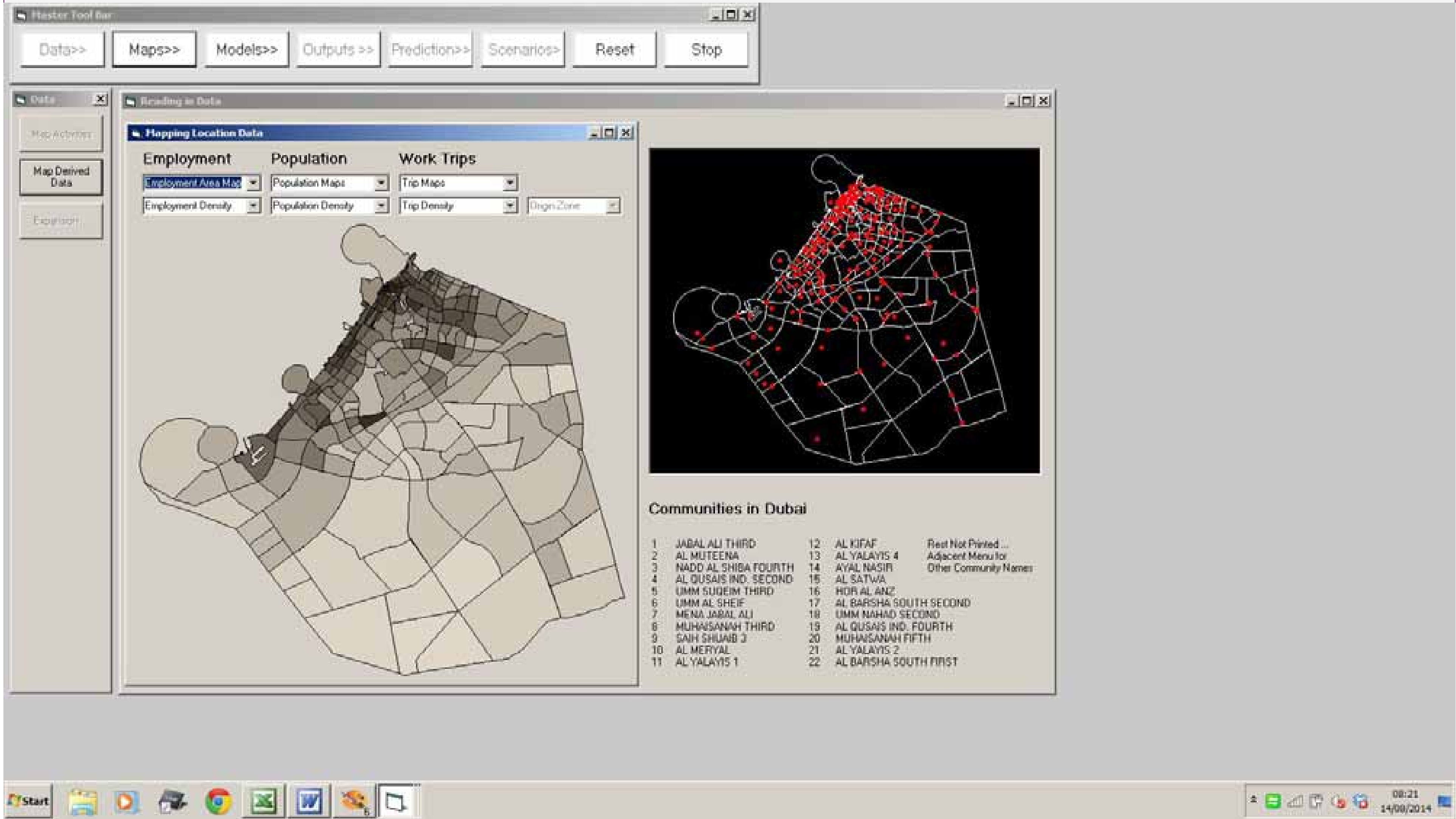
Adjacent Menu for
Other Community Names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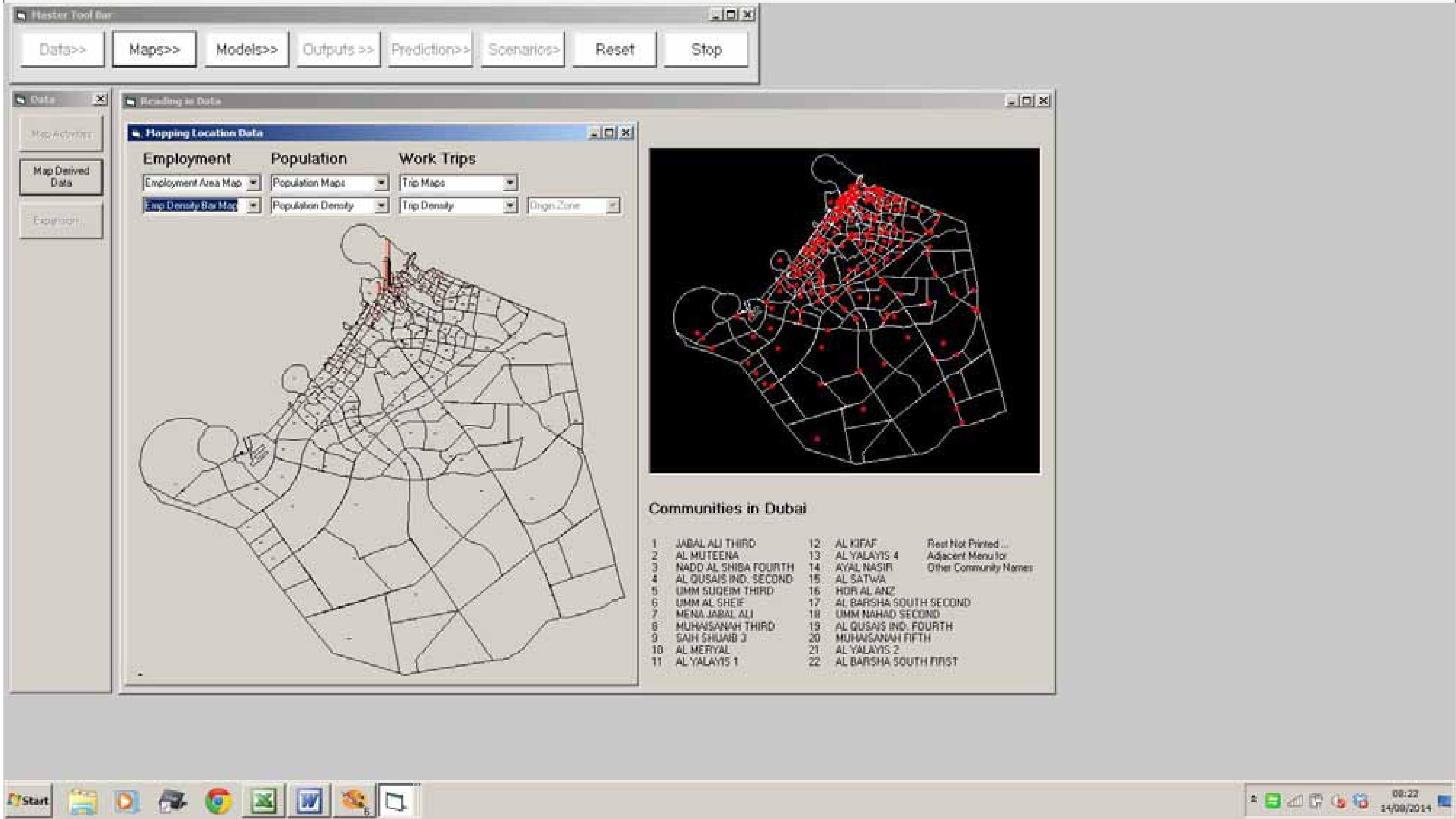
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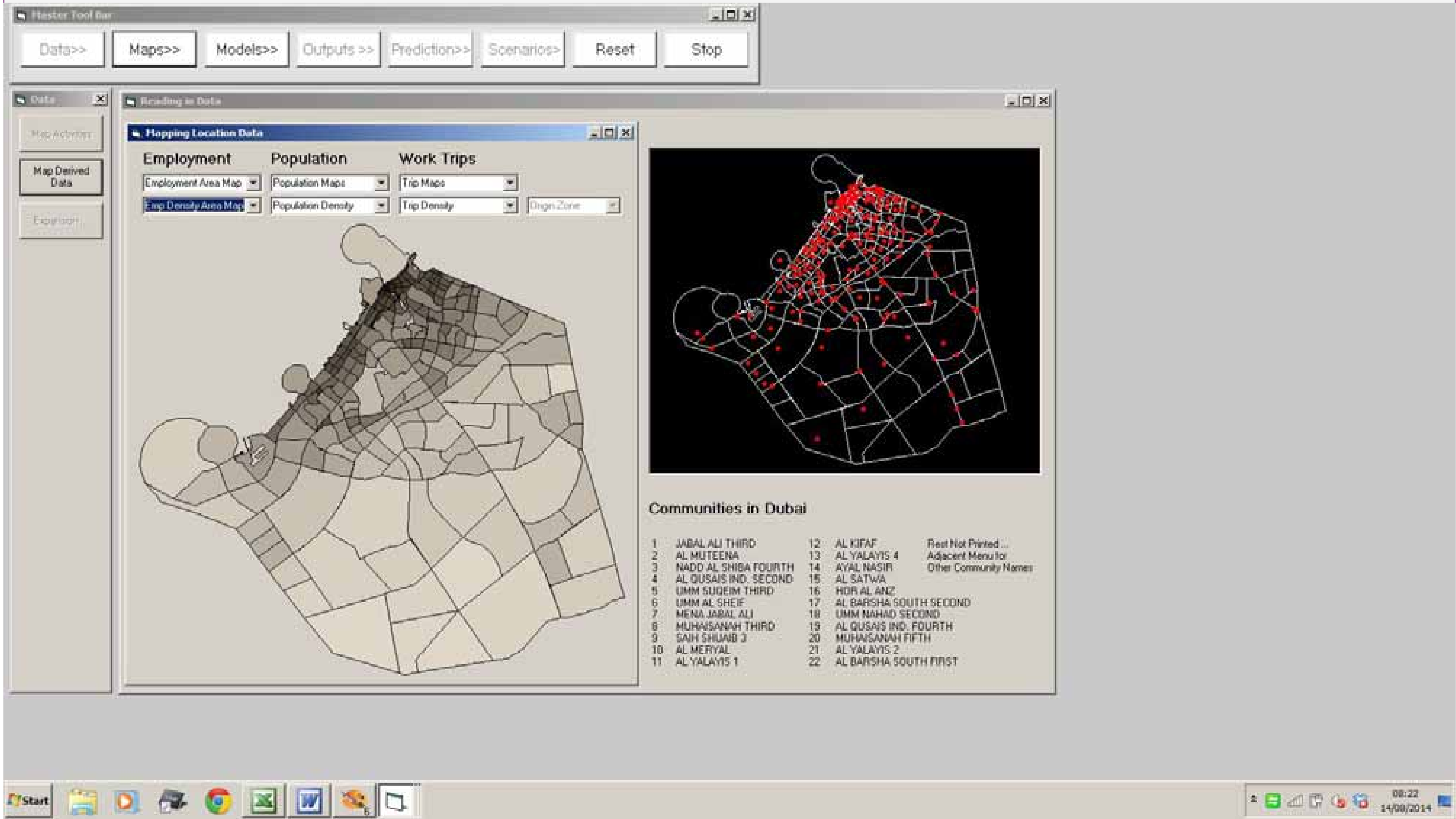
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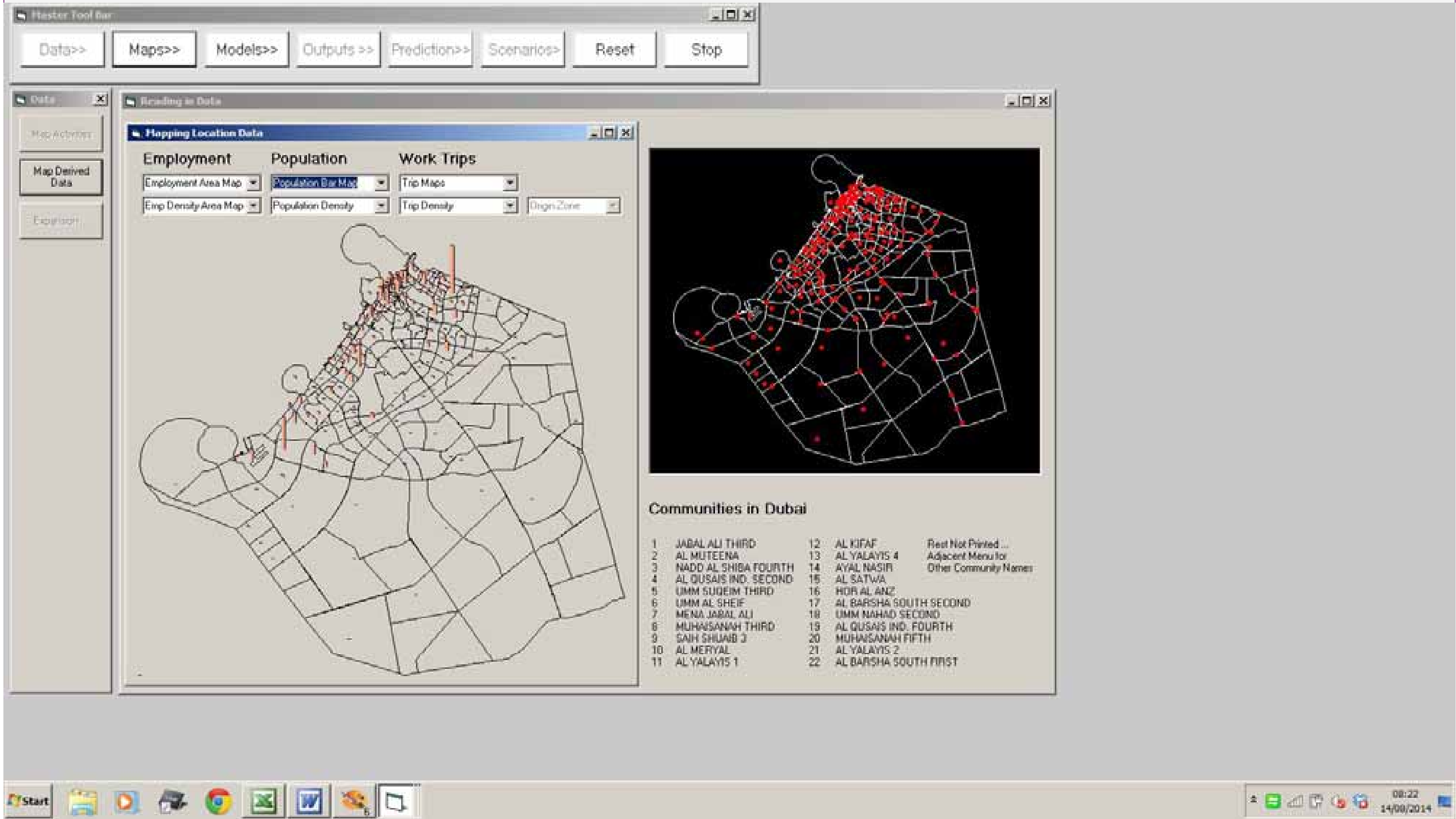

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Reading in Data
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Population Bar Map
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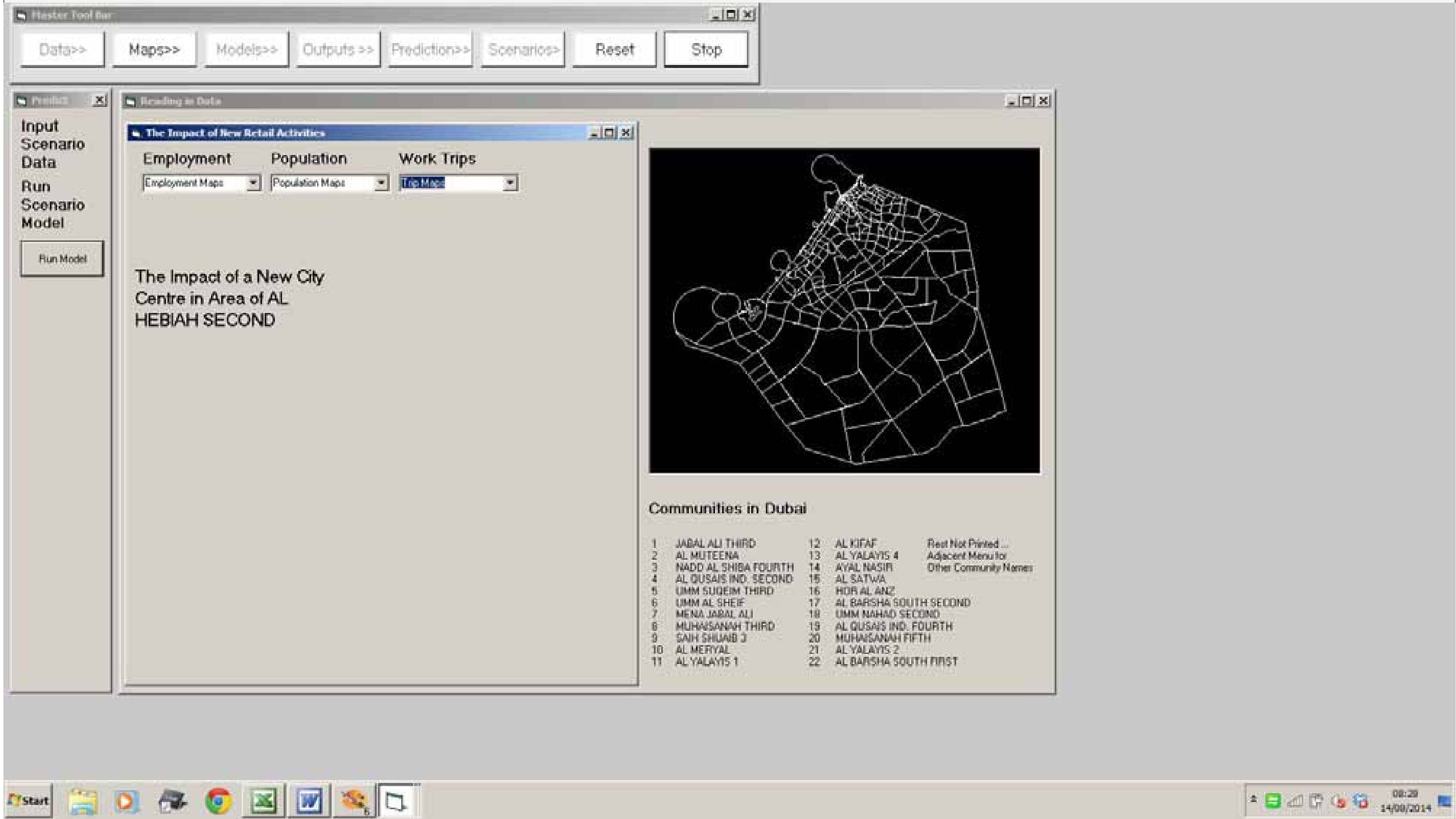
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Employment Maps
Population Maps
Trip Maps
The Impact of a New City
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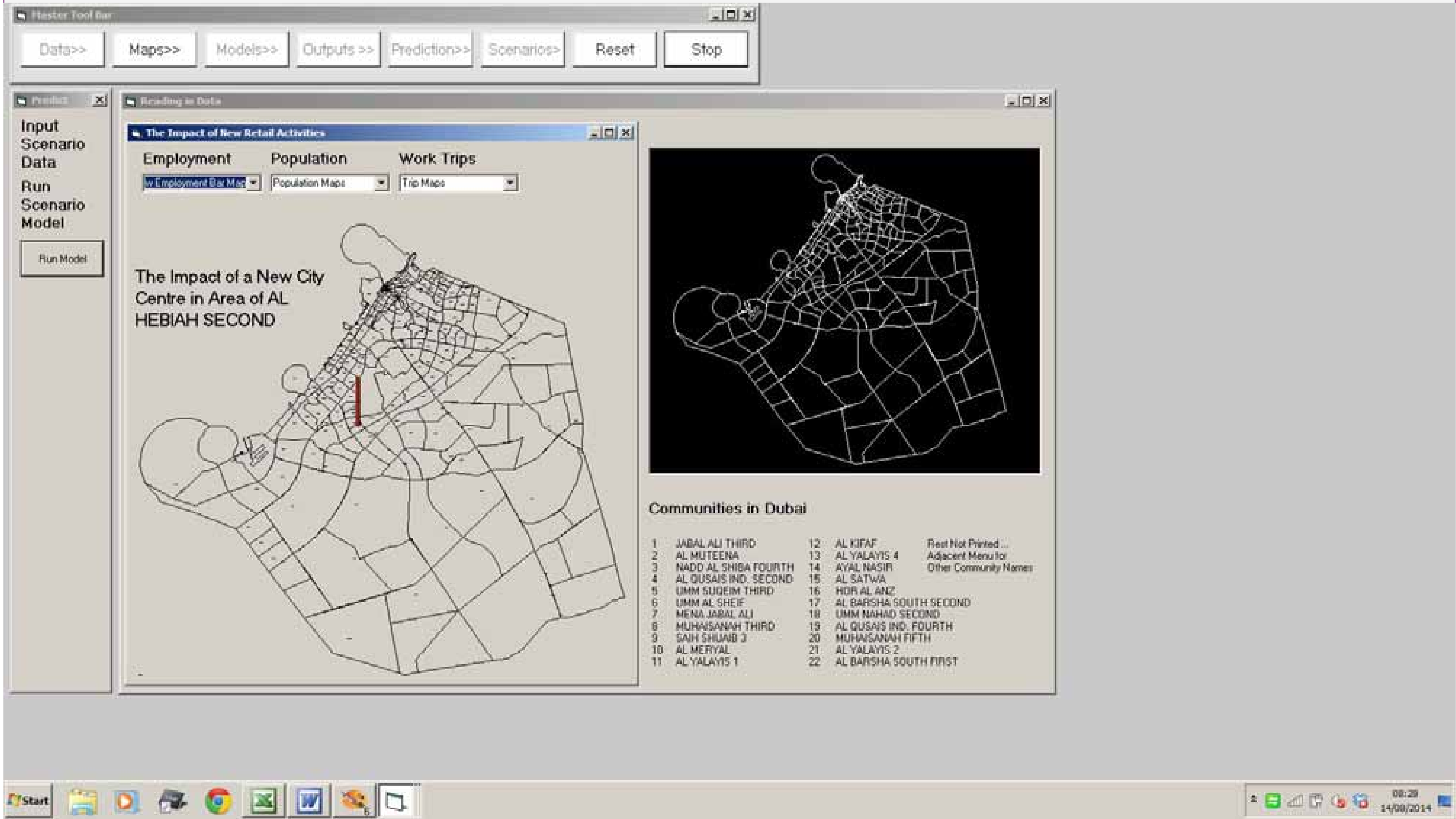
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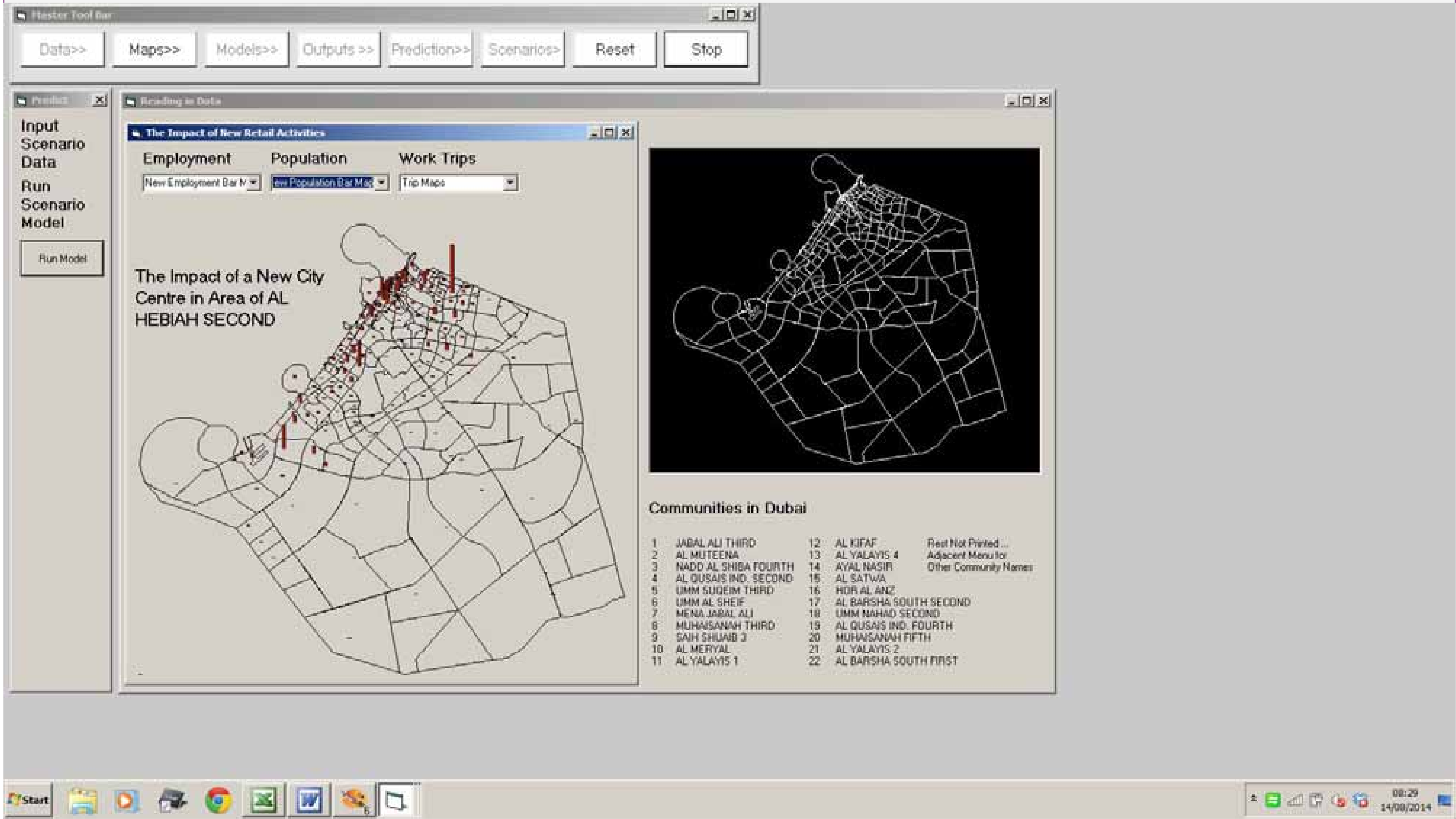
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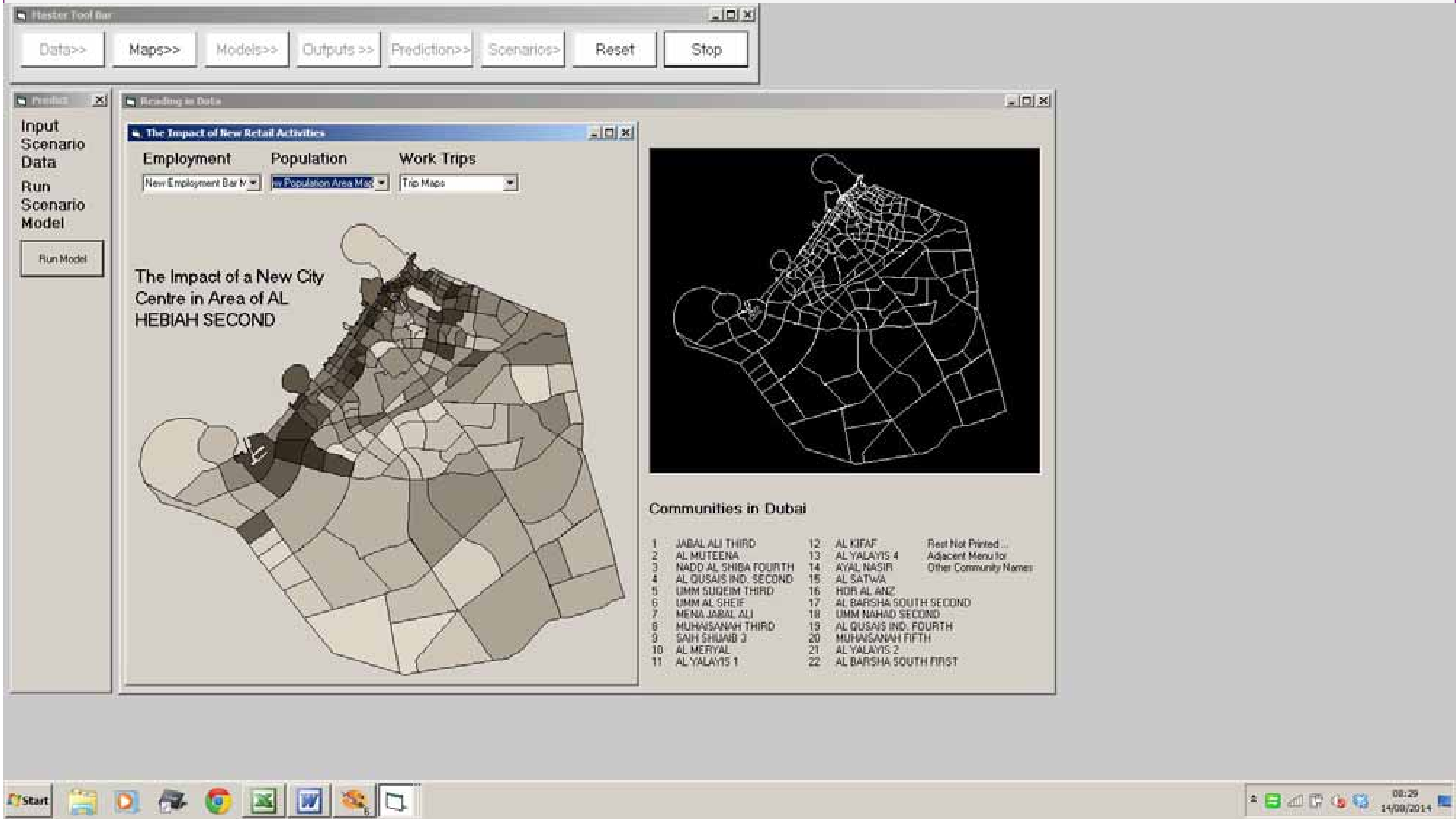

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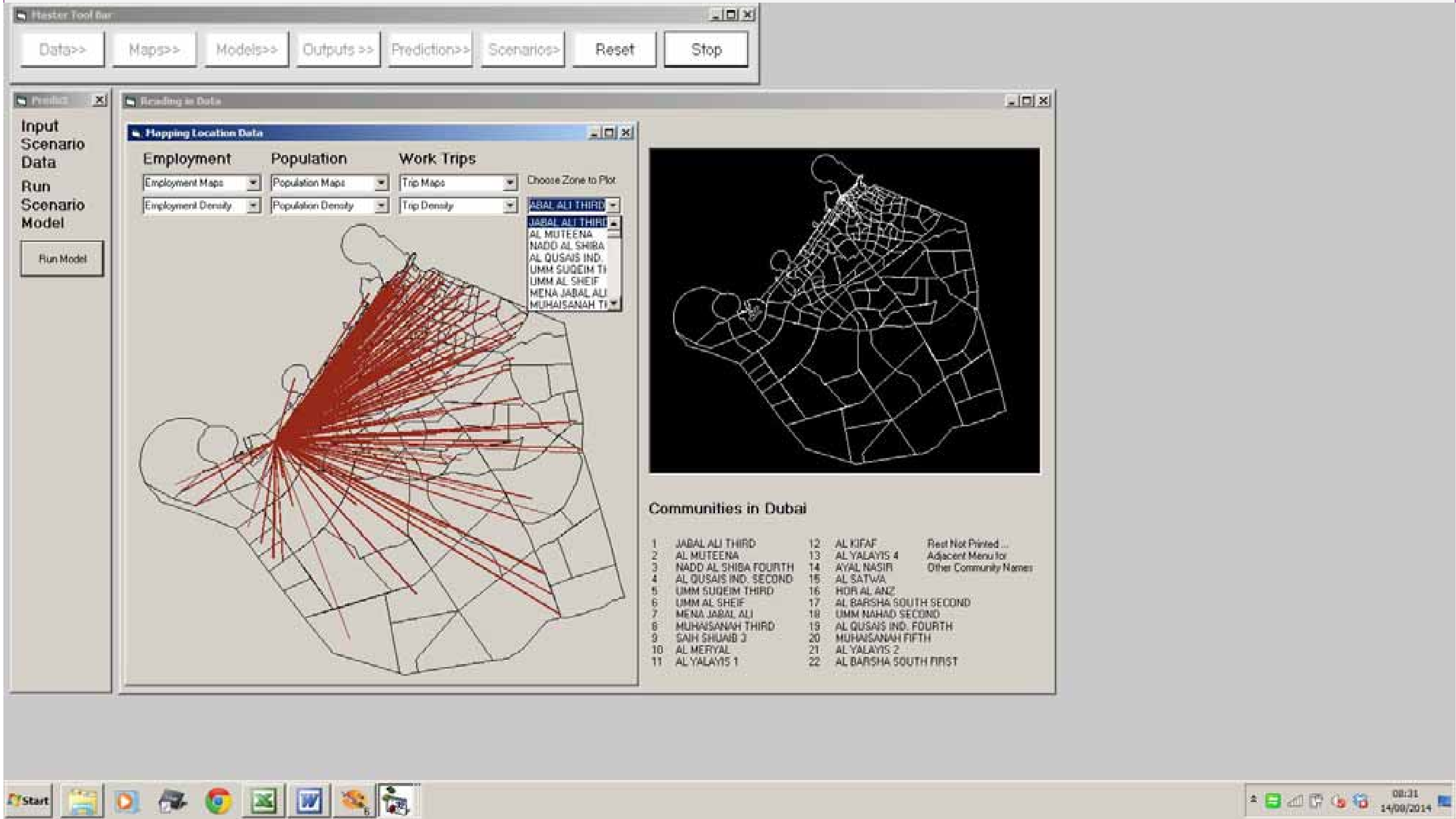

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Reading in Data
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Employment
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Work Trips
Employment Maps
Employment Density
Population Maps
Population Density
Trip Maps
Trip Density
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AL MUTEENA
NADD AL SHIBA
AL QUSAIS IND.
UMM SUQEIM TI
UMM AL SHEIF
MENA JABAL ALI
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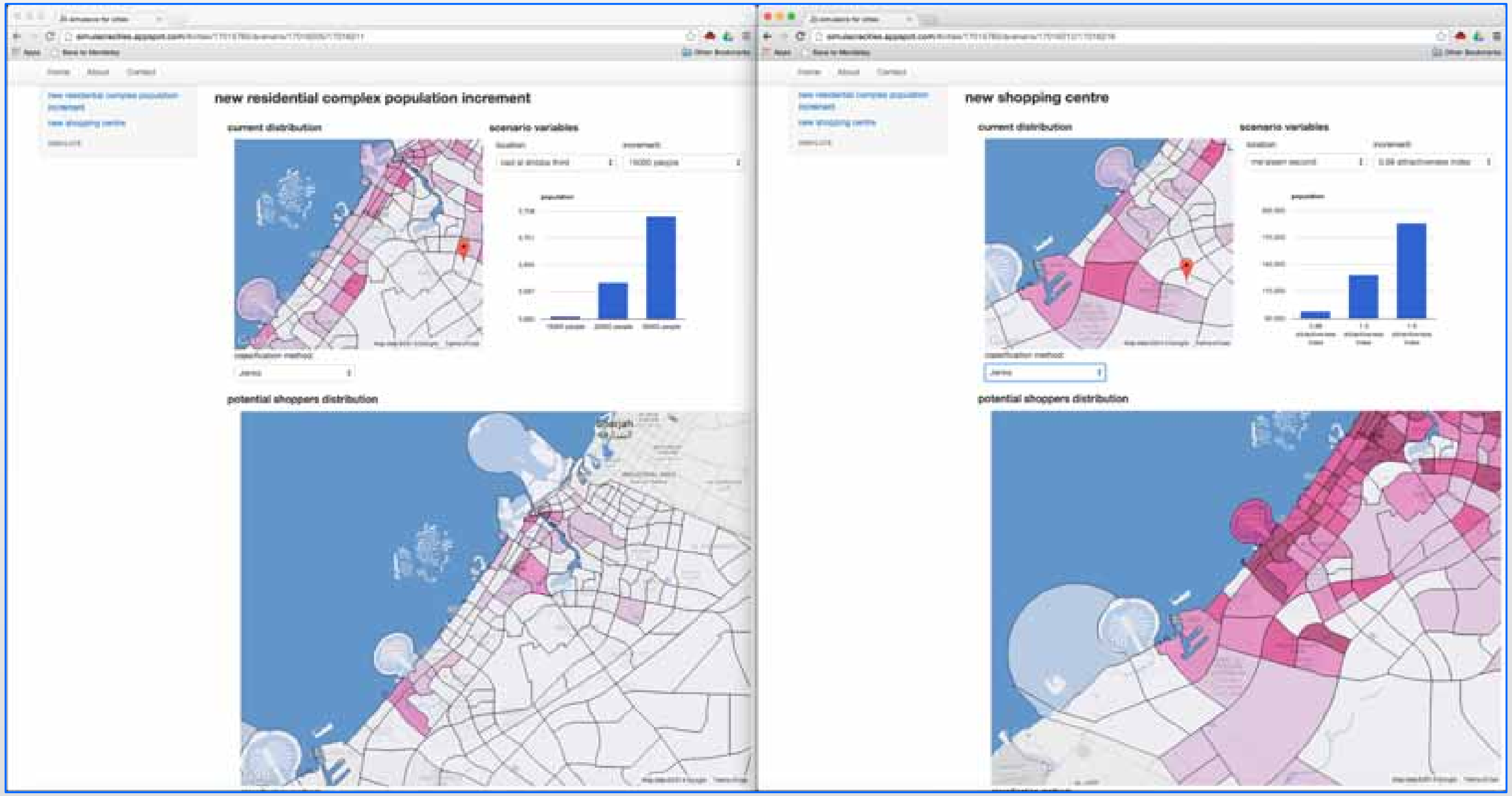
Applications

A New Retail Centre in Dubai



Lectures on Urban Modelling January 2017

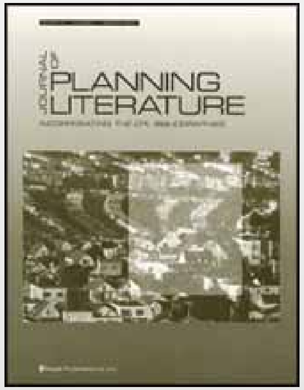
Thanks – The Last Lecture, Next Monday, same time

Michael Batty
m.batty@ucl.ac.uk
@jmichaelbatty

19 January, 2017

http://www.spatialcomplexity.info/

Reading about integrated models is more tricky as these models are convoluted – involved – that clear statements are hard to find. Two papers are relevant.



Iacono, M., Levinson, D., and El-Geneidy, A. (2008) Models of Transportation and Land Use Change: A Guide to the Territory, **Journal of Planning Literature**, **22**, 323-340, and

Hunt, J. D. , Kriger, D. S. and Miller, E. J.(2005) Current Operational Urban Land-Use-Transport Modelling Frameworks: A Review, **Transport Reviews**, **25**, 329 — 376

There is some good reading of all this material in Google Books in Button, K. J., Haynes, K. E., Stopher, P., and Hensher, D. A. (Editors) (2004) **Handbook of Transport Geography and Spatial Systems**, Volume 5 (Handbooks in Transport), Elsevier Science, New York