Spatial Thinking and Geographic Information Sciences

THE UNIVERSITY OF TOKYO

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Modeling and Simulation in Geographic Information Science:

Integrated Models and Grand Challenges

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http://www.ComplexCity.info/tweetpad/

Outline

- Modelling in GIS: Strict Requirements & Motivations
- Grand Challenges and Appropriate Models
- An Exemplar: Residential Location Models
- Visual Analytics and Modelling Processes
- The Economic-Energy Focus
- The Challenge of Energy: Rising Costs of Transport
- Integrated Assessment using Sketch Simulation
- Next Steps

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Strict Requirements & Motivations for the Models

1. Predictions:

Very long time horizons suggests that dynamics is less, not more important? Climate change wrt to sea level rise is relevant for 50 to 100 year forecast periods

Very short time horizons suggests the same: rapid changes in energy costs due to gasoline prices rises

Equilibrium models are useful to predicting responses where we simply do not know how the system will adapt

Such models address directly "What If" types of scenario

2. Stakeholder Involvement:

The need for *simple immediate models* that can be used over and over again to focus debate on "What If?" questions formulated as a dialogue

The need to explain model inputs, processes and outputs visually using maps etc as well as *visual analytics.* It is as important for stakeholders to understand the data as the model

3. Complex Problems over Many Scales and Fields:

Integrated assessment – wrt to climate and energy change – melding physical with social and economic – the need for visual analytics to communicate with scientists from different fields and to identify potential errors in extensive data sets

The need for simple fast models in all of this

4. Flexibility in Model Design and Extension:

The need for developing new but related models quickly retaining with powerful visualisation

The need to tailor models to questions and data which can be defined by stakeholders quickly and often casually

The need to evolve and build more dynamic model types

5. The Need to Embrace Organisational Constraints:

To build models understood by all members of the Consortia, stakeholders and scientists alike, where the process is dominated by resource constraints, different expertise in different locations, and by stakeholders directly defining the problems and absorbing the predictions. *All this implies, fast, simple, visual, and accessible models*

Grand Challenges and Appropriate Models: SIMULACRA

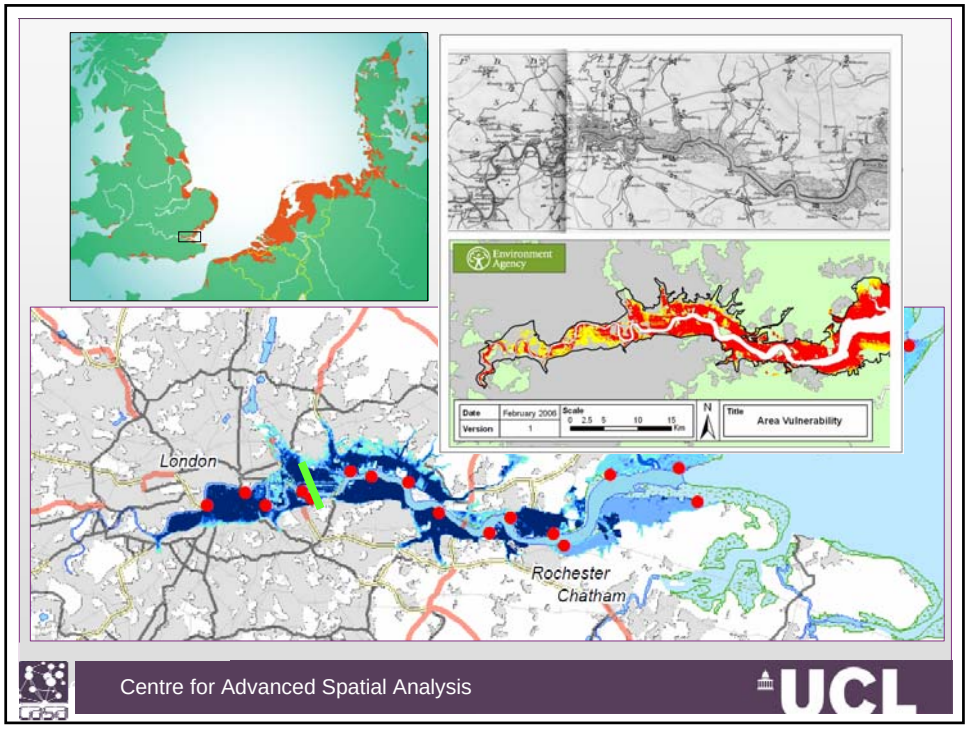
It builds immediacy, accessibility, and visual model operation

It starts from simple models such as the one I will describe here and it will progress to more complex models

It will deliver models on the desktop but through the web

It will build several related models at different levels of disaggregation for the London region, focusing on climate change (Tyndall and ARCADIA), energy change (SCALE) and major policy drivers such as Cross-Rail, the Olympic Games and major retailing developments (GENeSIS)

We will illustrate our first model that has been built for Tyndall


Environment Agency
Date February 2006
Version 1
Scale 0 2.5 5 10 15 Km
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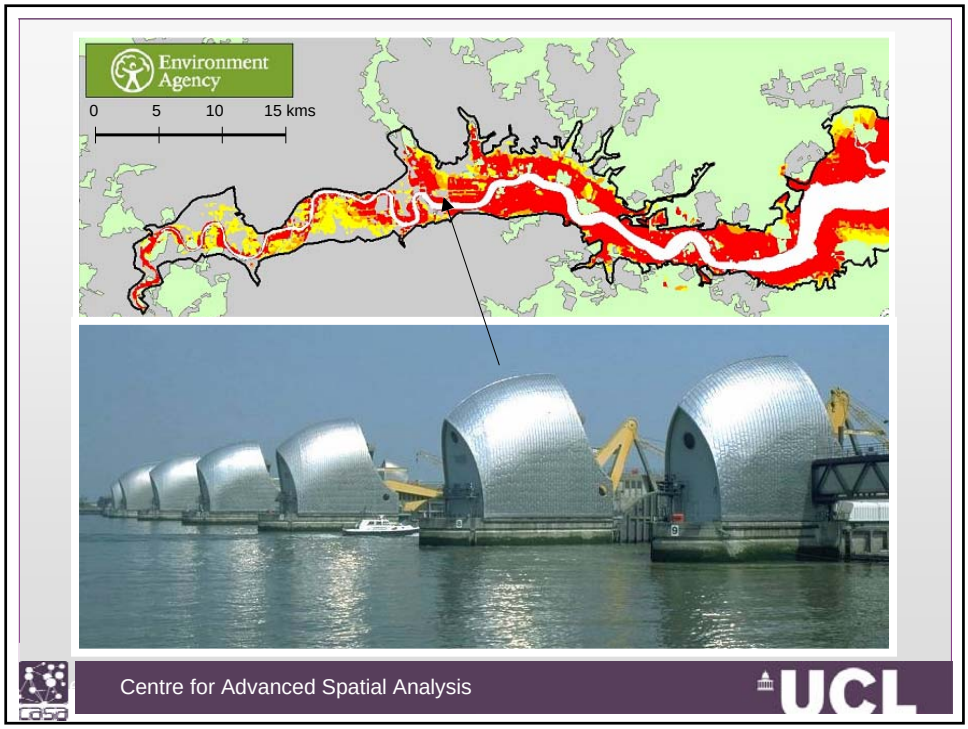
Title Area Vulnerability
London
Rochester
Chatham
Centre for Advanced Spatial Analysis
UCL


Environment Agency
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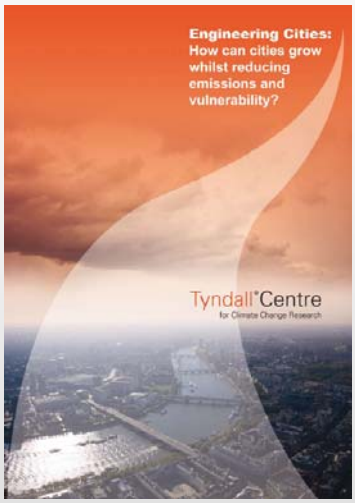
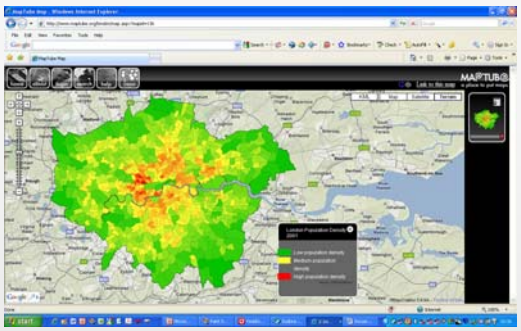
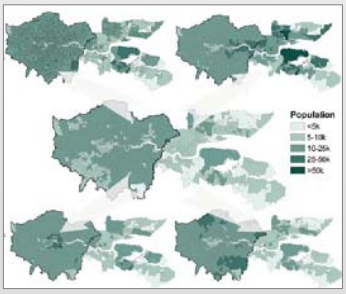


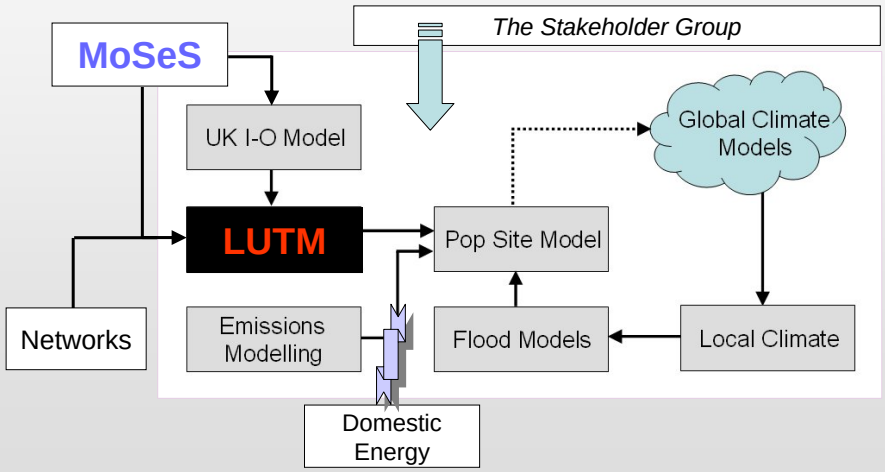




The IPCC forecasts moderated by UKCiP suggest North Sea will rise 2m by 2010, hence serious flooding of Central and East London

The Thames Barrier built 1978 to 1984 in operation, likely to be ineffective by 2040? due to new predictions of sea level rise forecast at 1-2 metres by 2100 – somewhat debatable, but ….

The model sits lies at the core of a process of chaining models together built by different groups and coming from different traditions



An Exemplar: The Residential Location Model

- is formulated as a four mode residential location model, origin constrained but subject to capacity constraints, with competition between locations and modes of travel determined respectively by land availability and travel costs.
- Land availability enables the model to consistently account for dimension trips so that there are consistent with their density
- The capacity constraints are introduced exogenously and can be formulated as policy levers but this as in all such model application introduces a degree of arbitrariness.
- The modes are road, bus, heavy rail and light rail (Tube and DLR)

The model can be written in conventional form as

Interaction:
$$T_{ij}^{m} = E_i \frac{A_j \exp(-\lambda^m c_{ij}^m)}{\sum_j A_j \sum_m \exp(-\lambda^m c_{ij}^m)}$$

Mode split on each link:
$$\frac{T_{ij}^{m=1}}{T_{ij}^{m=1}} = \frac{\exp(-\lambda^{m=1} c_{ij}^{m=1})}{\exp(-\lambda^{m=2} c_{ij}^{m=2})}$$

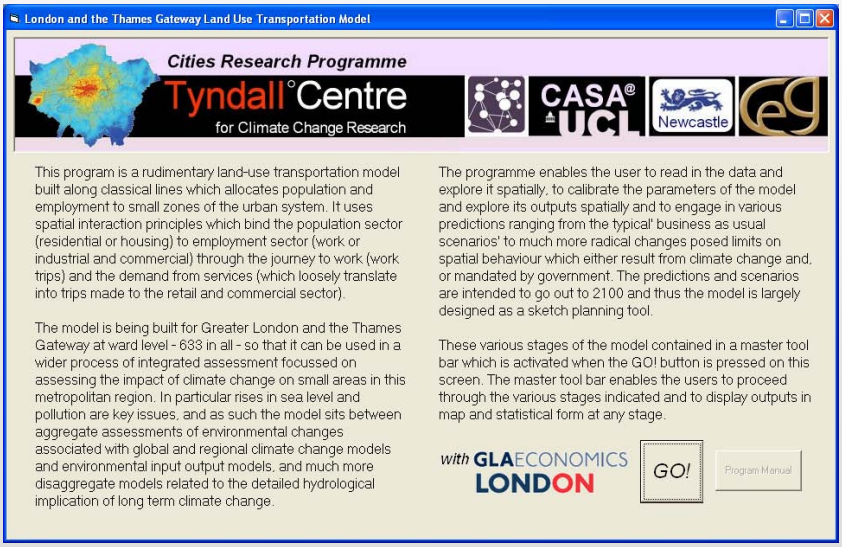
Total Mode Split:
$$\frac{T^{m=1}}{T^{m=2}} = \frac{\sum_{ij} T_{ij}^{m=1}}{\sum_{ij} T_{ij}^{m=1}} = \frac{\sum_{ij} \exp(-\lambda^{m=1} c_{ij}^{m=1})}{\sum_{ij} \exp(-\lambda^{m=2} c_{ij}^{m=2})}$$

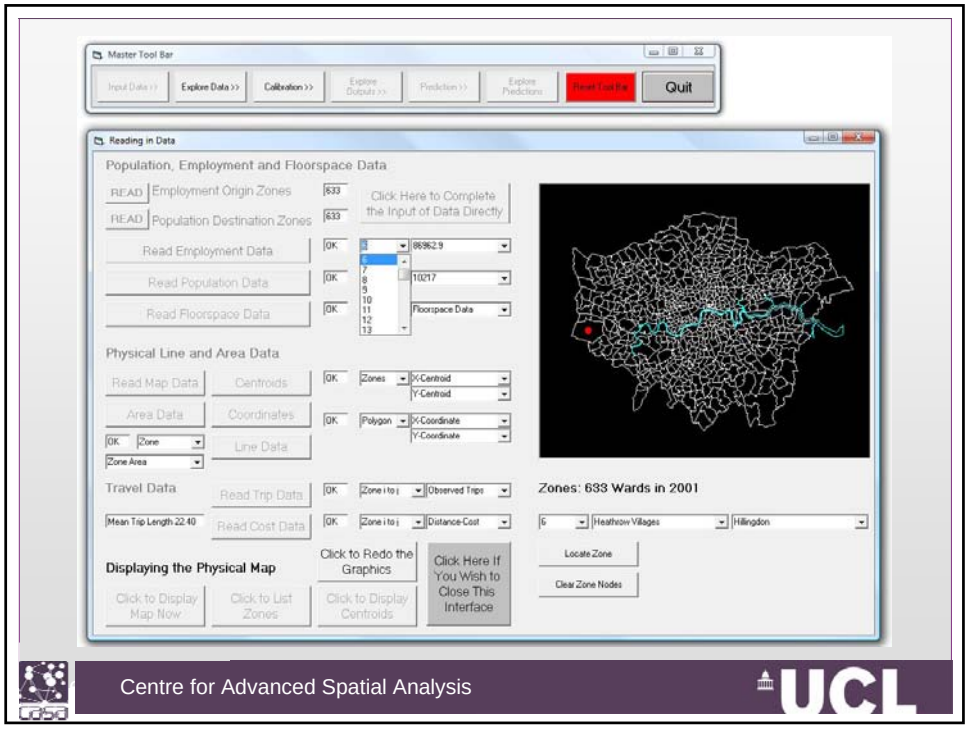
Residential Location:
$$P_j = \sum_{im} T_{ij}^{m}$$

And it is calibrated by solving the associated maximum likelihood equations. You can find these in my 1976 book ……

- There is an option which will be implemented in the version to be used to look at energy changes for equilibrating the transport flows with respect to capacities
- The model package is structured as a sequence of:
  1. Data exploration
  2. Model calibration and validation, and thence
  3. Prediction
- At each stage, the user can engage in extensive analysis of data, calibrated outputs, or predicted outputs
- This version model is calibrated to mean trip costs
- The entire process is visually driven and I will first show some screen shots before running the model

Visual Analytics and Modelling Processes





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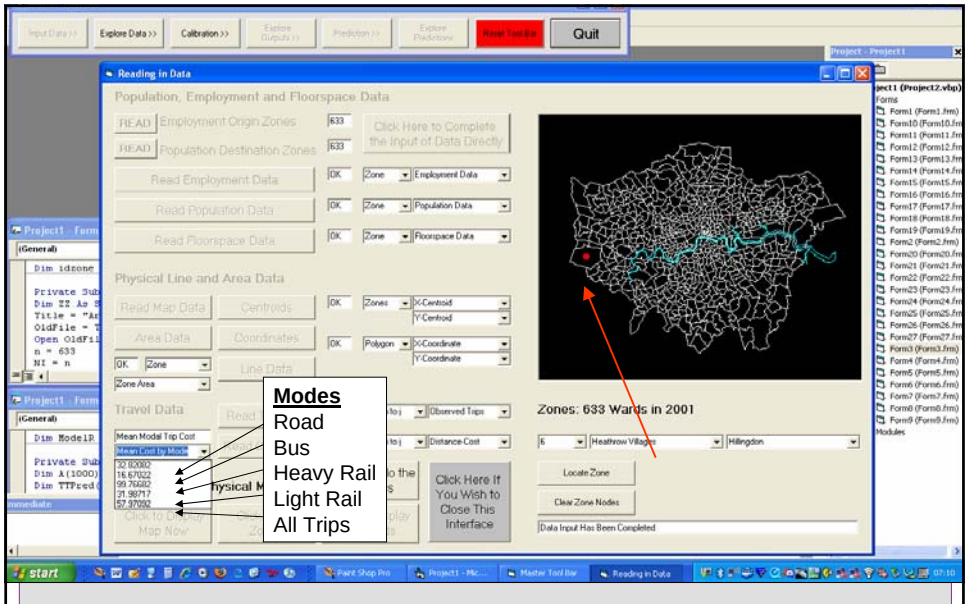

Road: 38%; Bus: 12%: Heavy Rail: 12%: Light Rail 19%; Other (Walk, Bike, Fly): 19%

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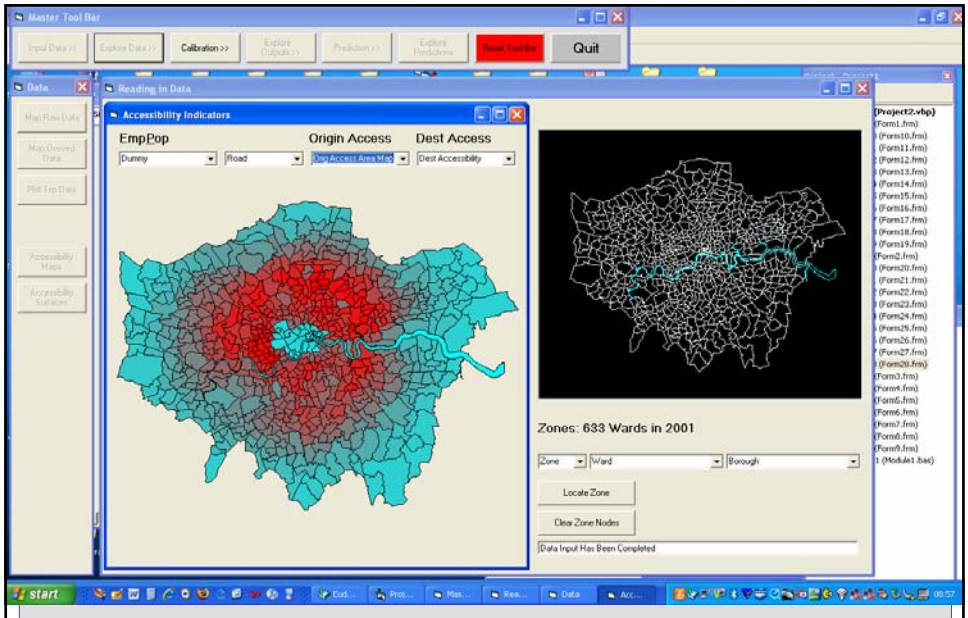

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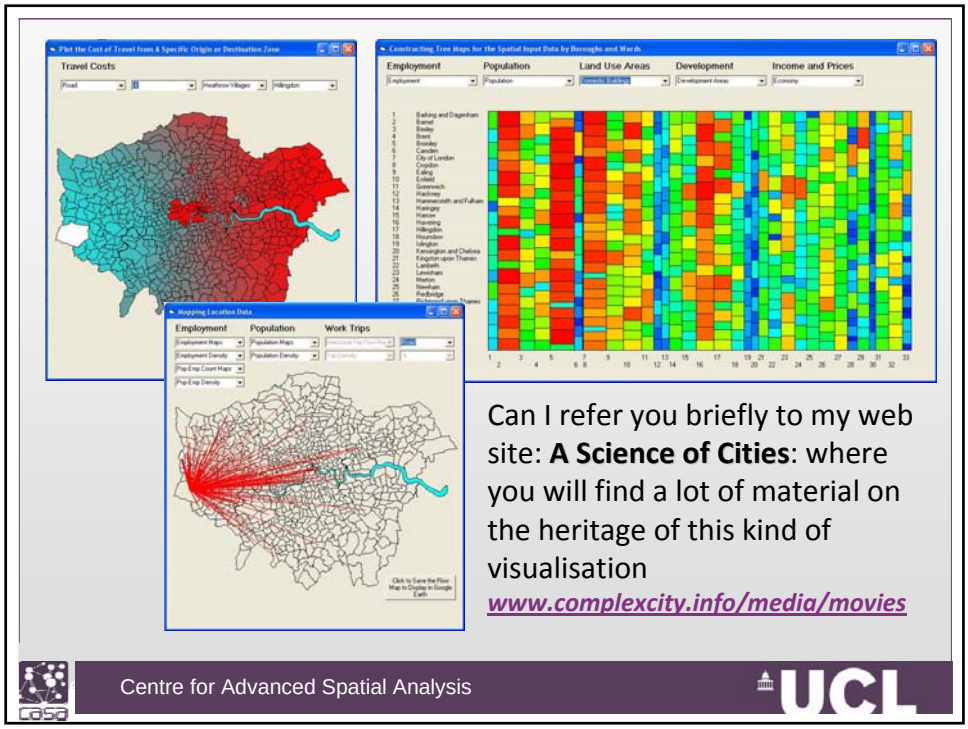

Can I refer you briefly to my web site: **A Science of Cities**: where you will find a lot of material on the heritage of this kind of visualisation
www.complexcity.info/media/movies

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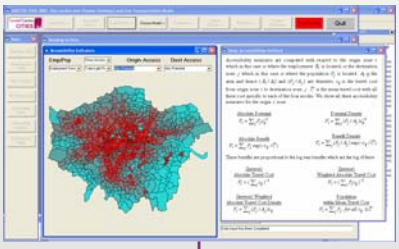
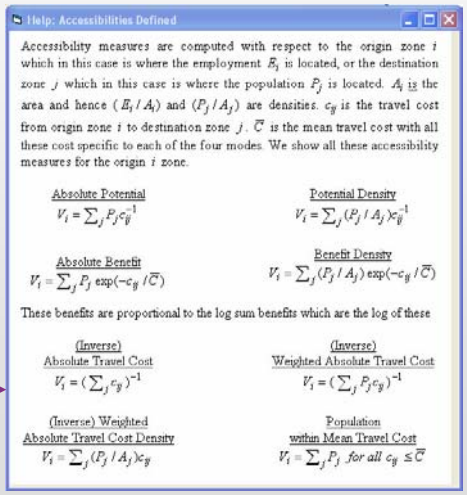
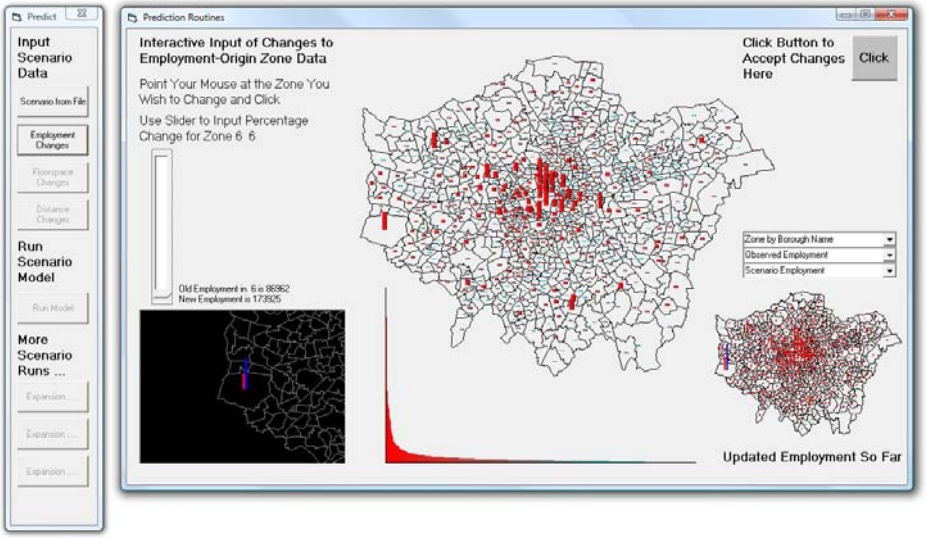
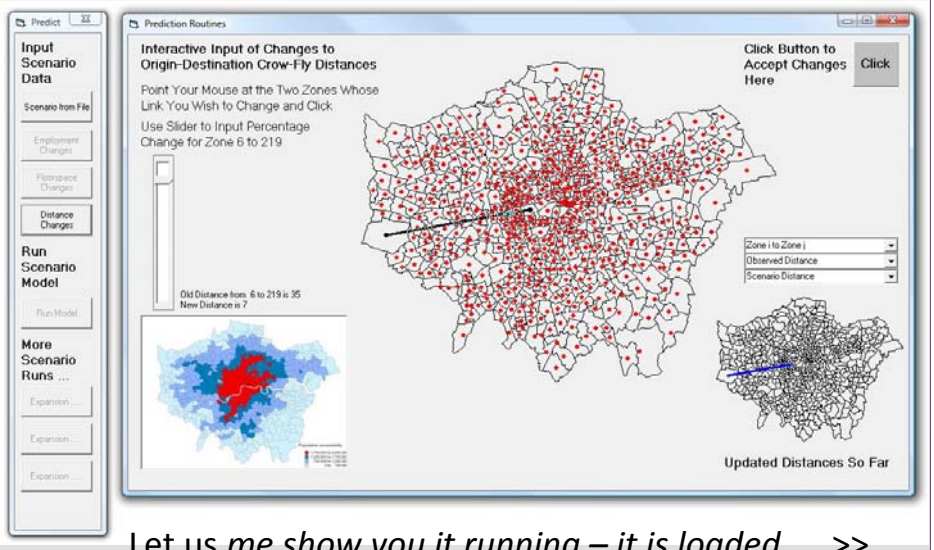
Accessibility from the LUTM model

Many different accessibility measures, 8 in all









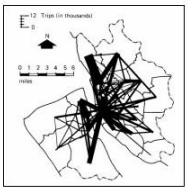
Let us *me show you it running – it is loaded* …>>

Run

For several movies of all our models go to www.complexcity.info/media/movies Drill down to find

Early Computer Movies: 1967 to 1990

Here we show how crude movies of urban development were fashioned from SYMAP plots stitched together using crude in-betweening. And then we move onto pixel arrays on PCs and VDUs – visual display units – attached to mini and even main frame computers, which ultimately turned into work stations by the early 1990s.



Urban Models (LUTI)

These are land use transportation interaction models that in our context evolved from early visual representations developed on workstations and then PCs. The Tyndall model and its successor ARCADIA are the key examples we show here. We have linked them to 3D media (Google Earth) loaded on the fly as these simulations proceed.

And now a little bit more about the model ……looking at the version we are currently building

The Economic-Energy Focus

- We have replaced the simple travel cost function with one that relates to wages, travel cost and housing cost
- In essence, we compute the proportion of a wage in any origin (employment zone) which is available for a) travel and b) housing, and we separate housing and travel costs into energy and non-energy related components
- Monies for travel are then compared to the actual travel cost on any link and those closest to the cost have a greater probability of determining a trip
- Monies for housing at origin i are then compared to the actual house price at location j and those closest to the housing price have a greater probability of determining the trip

- The model is built around variances between monies available for travel and housing and the actual costs of these as

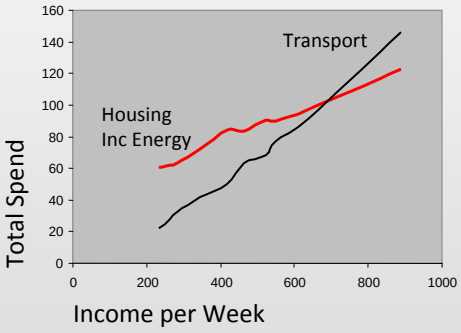
Interaction:

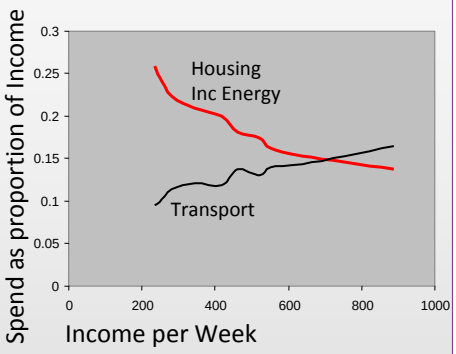
$$T_{ij}^{m} = E_i \frac{A_j \exp(\alpha p_j)\exp(-\lambda^m c_{ij}^m)\exp(-\beta(p_i(w)-p_j)^2 \exp(-\beta(c_i(w)-c_{ij}^m)^2}{\sum_j A_j \exp(\alpha p_j)\exp(-\beta(p_i(w)-p_j)^2 \sum_m \exp(-\lambda^m c_{ij}^m)\exp(-\beta(c_i(w)-c_{ij}^m)^2}$$

- Again we solve the model from its maximum likelihood equations
- There are several variants of all these models which can be chosen in real time by the user based on different patterns and combinations of moments and related constraints
- We need to look at the data which is aggregate as we have wages at the origin end and income at the destination end

Transport & Housing Costs from the '09 Spending Survey

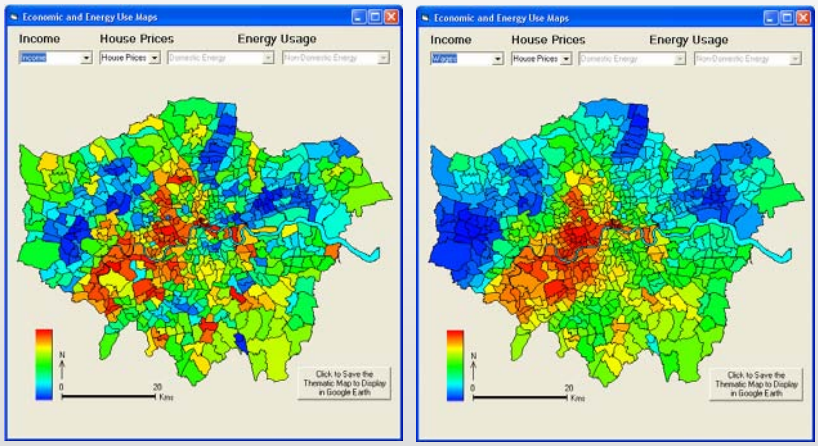
Here are the absolute costs





The above the relative costs to income

- Let is look at incomes where people live and wages where people work

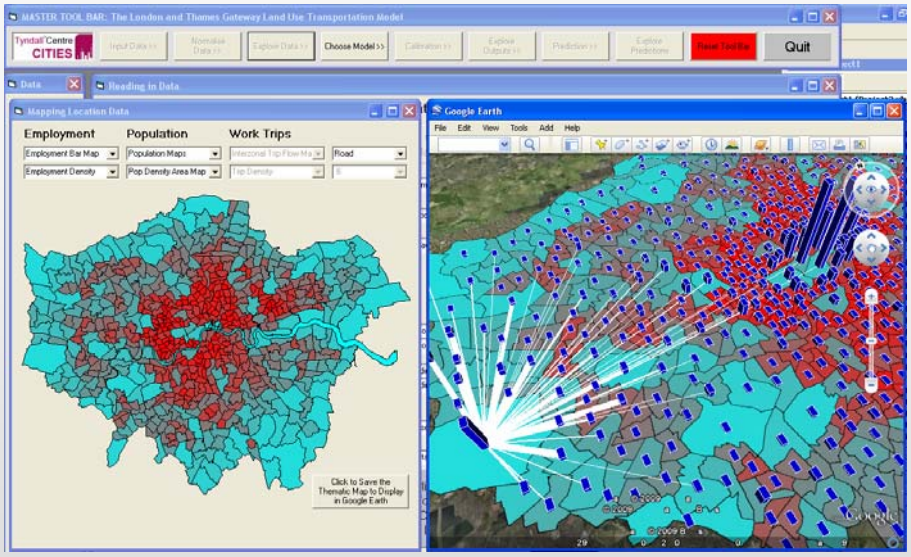


Extending the Software

- Currently we do not have good zoom, pan, overlay facilities in the model due to difficulties of such programming in VB. I suspect these could be developed but we also need to share the data and the predictions and a quick possibility is to use a non-proprietary open map visualisation system to link on the fly to the model: this should be web-based
- The best way forward at present is to generate KML files in the program and then feed them to Google Earth where we have overlay, 3D, and external data facilities. You have seen this.

- In this way, we can extend massively our ability to visualise as well as providing a storage facility for the model input and output data
- What is impressive about this is that the speed of doing all this is not slower than the interactive program in VB

It is based on pragmatic use of available software but it generates familiarity. It also lets us store data in a convenient fashion and add other external data as KML files – particularly physical data which is hard to store in the customised software



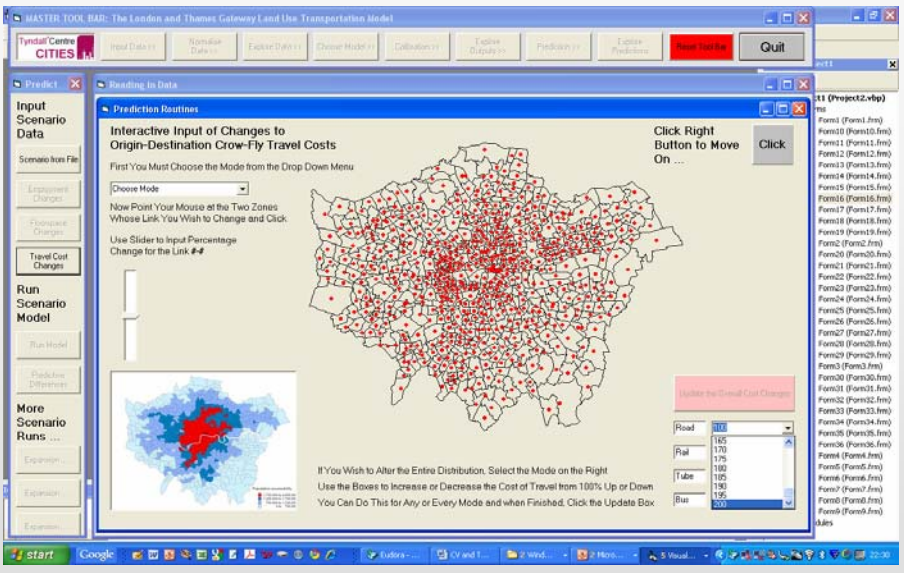
The Challenge of Energy: Rising Costs of Transport

I now want now to show you how we are using the model to handle energy costs in terms of rising costs of transport

What we can do is increase the cost of gasoline for road users relative to other modes and see what the effect is

If we double the cost of gas we then can see how users shift mode of travel and also how location of the population changes. The key issue is to assess this kind of shift in terms of interaction and location

We will show some screen shots of the model doing this



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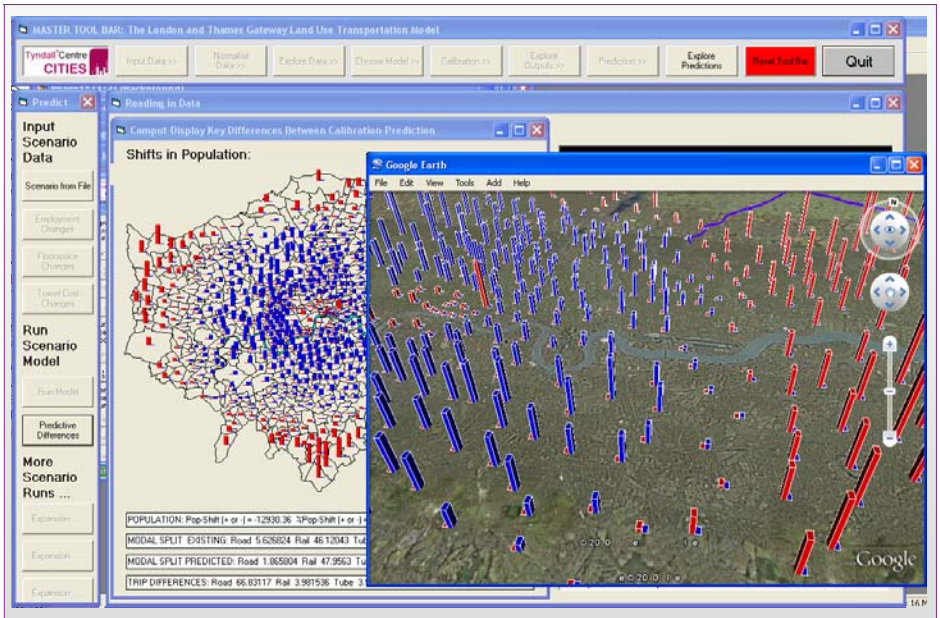

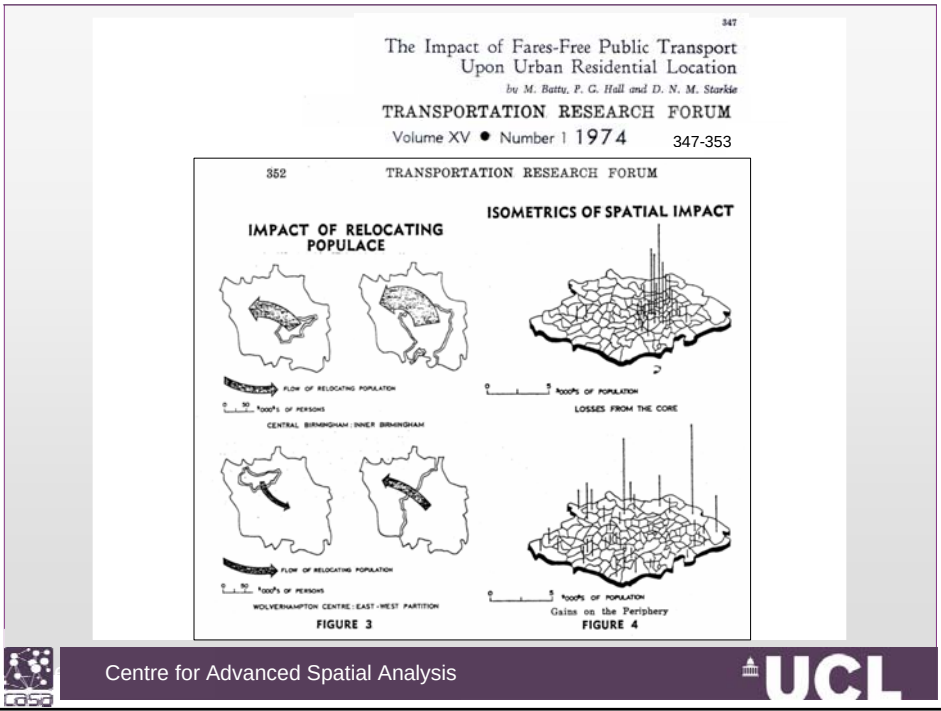

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The Impact of Fares-Free Public Transport Upon Urban Residential Location

by M. Batty, P. G. Hall and D. N. M. Starkie

TRANSPORTATION RESEARCH FORUM

Volume XV • Number 1 1974 347-353

352 TRANSPORTATION RESEARCH FORUM

IMPACT OF RELOCATING POPULACE

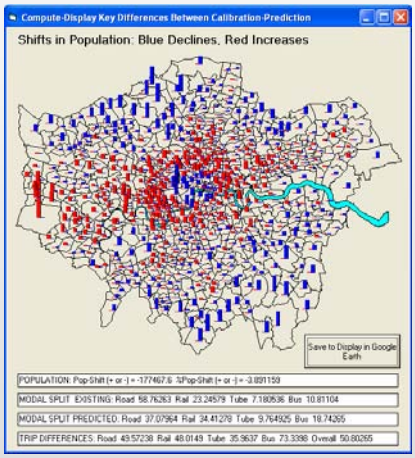
ISOMETRICS OF SPATIAL IMPACT

FIGURE 3

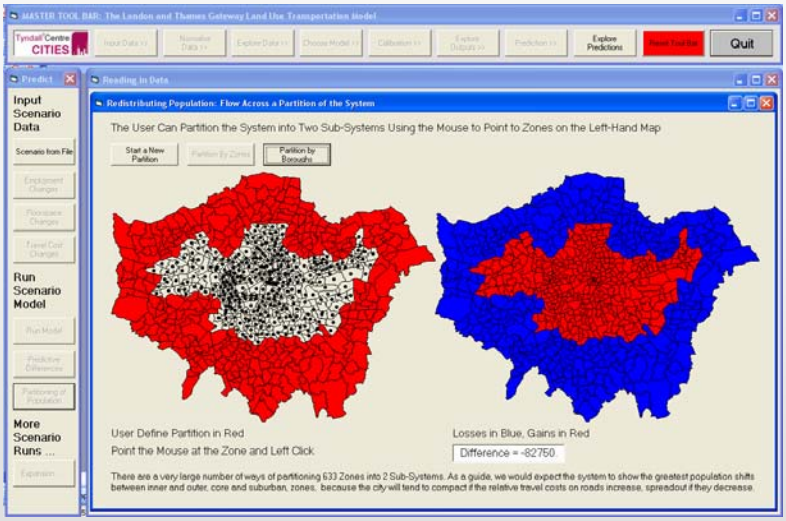
FIGURE 4

Gains on the Periphery

- The following figures show what happens if gas costs rise by 100% i.e. double



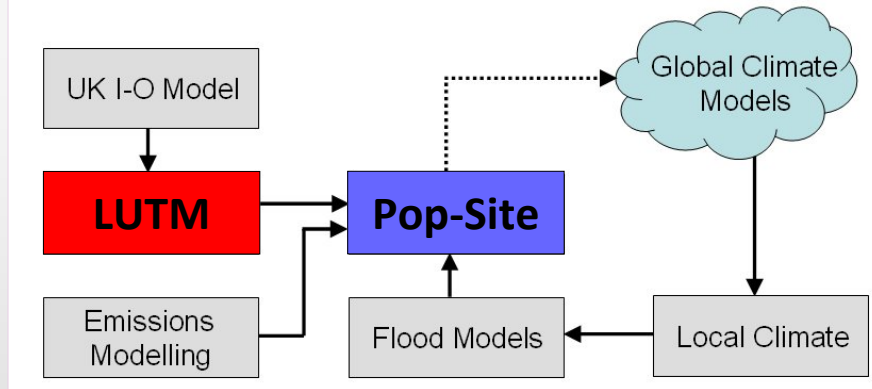
Mode	*Observed*	*Percent Shift*
Road	39%	-50%
Rail	12%	+48%
Tube	33%	+36%
Bus	16%	+73%
Population Shift		4%



Loss of Population from the Suburbs to central City – i.e. Big increases in travel costs on the road lead to compacting

Integrated Assessment using Sketch Simulation

- I have said nothing at all about how this model is embedded in the integrated assessment – the string of models that are used to scale national regional forecasts to very small scale. I cannot show you all these models but let me just talk briefly about the next stage down – how we go from 633 zones in London to 50 metre grid squares and this sort of hooks up to another style of modelling
- In GIS ….. Here is the integrated assessment block diagram again



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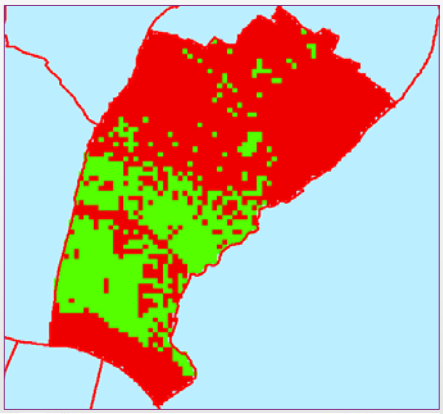
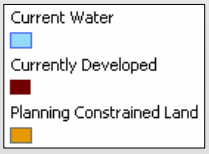
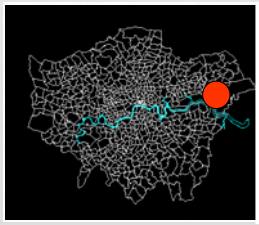
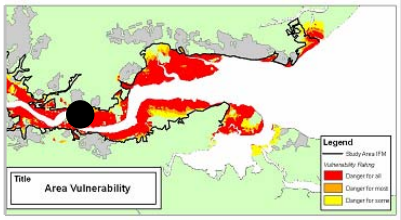
The local development model
GIS layers at 50 metre resolution









Next Steps

- Extending the area to 2000 or so zones – wider south east region
- Building the extended set of sectoral models
- Building in market clearing and some simple dynamics
- Extending the energy use to locational factors
- Disaggregating the model into more population and employment types relative to data
- Specifying movers and stayers through the exogenous inputs and tying these to past model outputs

If there is time,

I will answer any

Questions

www.casa.ucl.ac.uk

www.ComplexCity.info/tweetpad/

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