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Beijing Urban Spatial Development Model Families: From Macro, Meso to Micro Level

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Applied urban modelling (AUM)

This report falls into the pool of AUM
  o Rather than theoretical urban modelling

Increasingly complex urban system
  o Residents, firms, buildings, parcels, policies, laws, standards and regulations
  o Integrated platform required for handling various aspects, giving thanks to the booming of IT
  o Man brain not applicable any more, of decision makers, planners even modelers

City lab for testing policies
  o Evaluation
  o Forecasting
  o Scenario analysis

Dozens of extensively applied approaches in existing researches
  o Various spatial scales
  o Structural, static and dynamic
  o Top-down vs. bottom-up
• Structure models
• Static models (most are top-down)
• Dynamic models (both bottom-up and top-down)
## Selected applied urban models

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**Selected applied urban models** (-cont.)
BUDEM Families

Beijing Urban Spatial Development Model

- Applied urban modelling
- Launched in 2007 and in development
- Supported by Beijing Institute of City Planning and Beijing Planning Commission

Macro-level (city-scale)

- Urban expansion analysis and simulation
- Cellular automata, 500*500 m

Meso-level (city-scale)

- Land use and transportation integrated simulation
- Residential / firm location choice
- Traffic Analysis Zones (TAZ)

Micro-level (parcel-scale)

- Spatial policy / energy / environment evaluation
- Microsimulation, parcels / households / firms
Study area of BUDEM

The Beijing Metropolitan Area (BMA)
Capital of P. R. China, northern china, adjacent to Tianjin and Hebei
16410 sqkm
  - mountainous: 10071 km²
16 district
Ring road 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 5\textsuperscript{th}, 6\textsuperscript{th}
Rapid urban expansion in Beijing

Land use of Beijing
- Interpreted from Landsat TM/ETM/MSS

The near future
- Both expansion and redevelopment
- Increasing urban redevelopment
  - Opportunity for micro model
Master plans in the BMA

Urban master planning of Beijing metropolitan area, as the capital city, since the foundation of P. R. China:
- 2004
- 1992
- 1982
- 1973
- 1958

The new master plan might be compiled in 2013.
All focusing on spatial

- Urban growth / expansion, redevelopment
- Urban form / urban structure
- Strong relationship between urban spatial organization and CO2 emission
  - Owens, 1987, Anderson et al., 1996; Banister et al., 1997
## Macro BUDEM (2006-)

<table>
<thead>
<tr>
<th>MACRO</th>
<th>MESO</th>
<th>MICRO</th>
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<tbody>
<tr>
<td>Identifying driving force of urban expansion in various historical phases</td>
<td>Evaluating the effectiveness of urban master plans in urban expansion</td>
<td>Retrieving policies required to implement master plan for 2020</td>
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<tr>
<td>Simulating urban growth scenarios with different policies set in 2049</td>
<td>Planning support system for practical urban planning and management (various developing policies)</td>
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An applied CA model

CA settings:
- **Cells**
  - $500 \times 500m$
  - 65628 cells
- **Cell States**
  - $V=1$ urban built-up
  - $V=0$ none urban built-up
- **Status Transition Rule**
  - Multi-criteria evaluation, MCE
  - Retrieved by logistic regression
- **Neighborhoods**
  - Moore
  - $3\times3$, rectangle, 8 adjacent cells
- **Discrete Time**
  - 1 iteration/step = 1 month

**Approaches**
1. Constrained cellular automata (CA)
2. Logistic regression
3. Regional sensitivity analysis

Urban growth from undeveloped to developed only
Driving forces of urban expansion

Select spatial factors using hedonic model

- **Location**
  - Minimum distance to hierarchical urban center
    - Tian an men $d_{tam}$ important new city $d_{vcity}$ new city $d_{city}$ important town $d_{vtown}$ town $d_{town}$
  - Minimum distance to wetland $d_{river}$
  - Minimum distance to regional road $d_{road}$
  - Minimum distance to ward (town level) boundary $d_{bdtown}$
  - Regional attraction of greater Beijing area $f_{rgn}$

- **Neighborhood**
  - Developing intensity in neighborhood $neighbor$

- **Government**
  - Urban master planning $planning$
  - Cultivating suitability $landresource$
  - Constrain zoning
    - Constructing forbidden area $con_f$

\[
V_{i,j}^{t+1} = f\left\{V_{i,j}^t, Global, Local\right\} = \left\{V_{i,j}^t, LOCATION, GOVERNMENT, NEIGHBOR\right\}
\]

\[
= f\left\{d_{tam_{i,j}}, d_{vcity_{i,j}}, d_{city_{i,j}}, d_{vtown_{i,j}}, d_{town_{i,j}},
    d_{river_{i,j}}, r_{road_{i,j}}, d_{bdtown_{i,j}}, f_{rgn_{i,j}},
    planning_{i,j}, con_f_{i,j}, landresource_{i,j},
    neighbor_{i,j}\right\}
\]
Model calibration

Logistic regression result of various historical phases

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Variable in different phases differ greatly (market and government balancing, macro-policy)

Common character: road directing developing, constructing forbidden area protected

- 2001-2006 river>new city>region
- 1996-2001 new city developing, slow town developing, negative regional influence
- 1991-1996 center city>city, planned area developing, agricultural land with high suitability encroached
- 1986-1991 new city promoted, agricultural land protected, planning promoted

Model validation: The simulation in 1986-2006 well replicates historical urban expansion, in terms of Kappa and spatial pattern.

*Significant at 0.001 level
1 Urban expansion scenario analysis for 2049

A. Macro socio-economic policy simulation

B. Planning scheme simulation
   - B1 Ring road 7th
   - B2 New eco-protection area
   - B3 City center shifting

C. Urban growth policy simulation

D. Specific policy simulation
   - Second international airport
   - Backup urban land develop
2 Establishing urban growth boundaries (UGBs)

- UGBs for the central city and 11 new towns, 142 towns not included
- Significant differing from planned UGBs in the master plan, with
  - Less expansion in the north
  - Different new towns layout
- High probability to be broken for planned UGBs in coming years

3 Urban planning implementation effectiveness

Fig. 3. Coefficients of all factors in various periods.

Fig. 4. Comparison of urban planning coefficients in various districts.

Fig. 5. Simulated urban forms by adjusting urban planning coefficient in BUDEM: the baseline scenario (left) and planning-strengthened scenario (right).
4 Identifying policy parameters for spatial plans

Couclelis (2005) argued that little has been done by routine land use models to investigate the future-oriented research, such as desired or feared future.

Our work

Form scenarios (Land use patterns)

Figure 6. Scatter plots of policy parameters identified for two combined constraints in the virtual space, when the $x$ axis is $x_1$, $y$ axis is $x_2$ and ‘accepted indicates’ $\kappa \geq 80\%$. (a) Form 1, possibility of the urban form $P = 0\%$; (b) form 2, $P = 17.8\%$; (c) form 3, $P = 46.4\%$; (d) form 4, $P = 17.8\%$. 

- Accepted
- Rejected
Our findings:
- Under current spatial policy settings, the spatial layout of master plan for 2020 could not be implemented.
- This module of Macro BUDEM could facilitate planners compiling a spatial plan with higher possibility to be implemented.

Backgrounds:
- Planned layout is occasionally broken through in China due to lack of consideration of economy factors
- Empirical studies in Beijing, Guangzhou, and Shanghai (Han et al, 2009; Xu et al, 2009; Tian et al, 2008)
5 The second international airport location choice

Baseline scenario

With the airport
6 Extended to the Greater Beijing Area
Meso BUDEM

Beijing Land-use and Transportation Integrated Model
- BLUTI v1.0
- Developed in 2009
- Long term forecast (2020)
- Based on Cube

178 TAZs

Applications in urban planning practices
- 3A Hospital site planning assessment
- Influence of subway Line 5 on housing location choice

Contributors
- ZHENG Meng, ZHANG Xiaodong, ZHANG Yu, ZHANG Xin in Department of Transportation Planning, BICP
Set the variable to compare the HH need and Residential RE supply.

Prepare the Real Estate Capacity.

Compare the HH need and RE supply.

Set modal split [Option] to 2 when do the full run!!
System structure of meso BUDEM

- **Transportation sub-models**: Trip Gen, Trip Dist
- **Land use sub-models**: Location Choice, Rent Model, Land Auction
- **Mode Choice**: Which mode?
  - By foot?
  - By bike?
  - By car?
  - By PuT?
- **Trip Generation (Trip Gen)**
- **Trip Distribution (Trip Dist)**
- **Mode Choice**
- **Traffic Assignment (Traffic Ass)**
- **Location Choice**
- **Rent Model**
- **Land Auction**
- **Develop Model**
Flow chart of meso BUDEM

- Scenario Land Use Plan Transport Sys
- Labor Market Balancing Check
  - Balance
    - Yes
      - Employment Distribution Labor Demand RE Planning
  - No
- Residential Location Choice
- Rent Model
- Develop Model
- Land Model
- Rental Market Rent Model
- Land Use Model LU Model

MACRO
MESO
MICRO

- Trip Gen
- Trip Dist
- Mode Choice
- Traffic Assg
- Acc
Applications:
1 Residential land scale and distribution appraisal
2 Forecasting the distribution of different household type
3 Forecasting the distribution of rent price
4 Forecasting the distribution of land price
5 Forecasting the accessibility
6 Forecasting the distribution of trips
7 Forecasting the traffic modal split

AM PH Modal split result
8 Forecasting the traffic volume through assignment

AM PH VC ratio of Planning Year
9 Balance between the labor demand and supply appraisal

Labor demand: 10 million
Pop demand: 18.6 million
HH demand: 7.2 million
HH supply: 7.6 million
Balance
In upgrading to 1911 TAZs using UrbanSim, focusing on residential and firm location choice.

Probability = $\beta_0 + \beta_1 \ln\text{POTENTIAL} + \beta_2 \ln\text{ACC} + \beta_3 \ln\text{D}_\text{SUBWAY}$
$+ \beta_4 U\_\text{PRICE} + \beta_5 O\_\text{DUMMY}$
Micro BUDEM

An ongoing project (city lab for testing policies)
- 2012-2014
- Expected to continue during the academic visit to University of Cambridge from March 2013 to March 2014

A fine-scale model for the whole Beijing Metropolitan Area
- Rather than limited to typical neighborhoods based on questionnaire
- Static parcels

Supported by macro and meso BUDEMs
- Providing exogenous variables for micro BUDEM

Proposal a fine-scale model for
- Establishing micro-level data infrastructure (BEIJING100%)
- Present
  - Environment, energy consumption, CO2, spatial policy
- Short-term
  - Demographic evolution, residential location choice, job location choice, land use layout scenario analysis
- Not applicable for long-term forecast or scenario analysis
BEIJING100% is 2010 based, and an extra evolution submodel will be proposed for short-term data synthesis in the near future.
BEIJING 100%: Parcels

Buildings
- Footprint & floor
- Within 6th ring road
- 2004/2006/2008/2010
- 254 million buildings in 2010

136638 existing parcels
- Floor area, land use type, resident count, job count

100912 planned parcels
- Land use type, FAR, maximum building height,

139886 cadastres
- Within 6th ring road

38894 land use permits
- 1950-2011
- Land use type, developer, issue date
BEIJING 100%: Population

19.1 m residents and 8.0 m households in the BMA

Input datasets:
- Samples (116,142 residents / 46,900 households)
- The 6th population census of Beijing
- Existing researches regarding statistical characteristics of population attributes and relationships among attributes

Population synthesis
- PopGen: based on samples and marginal
  - Developed by Arizona State University
  - http://urbanmodel.asu.edu/popgen.html
- Agenter: does not need samples
  - Developed by Ying LONG
BEIJING 100%: Population

- Samples
  - Aggregated data

Samples: F1, F2, F3, F4
Aggregated data: F1, F2, F3, F4, F5, F6
Pop. = Households + Residents

PopGen

• Aggregated data
• Existing researches

Agenter

Pop. F1-F4

Pop. F1-F6
Synthesized population

Resident attributes: age, gender, education, martial status, job, nation
Household attributes: size, income, location
A demographic sub-model to be developed to synthesizing short-term population.
**BEIJING100%: Human mobility**

### The Beijing Household Travel Survey in 2010

- 46,900 households / 116,142 persons surveyed
- 253,584 trips (52,640 commuting from housing to job)

Information including:
- Socio-economic attributes of households and persons
- One-day travel diary of each person (mode, purpose, OD, departure and arrival time, etc.)

### Converting trips to activities

- 75032 persons’ 287027 activities

### The 2005 version

- 81,760 households / 208,290 persons surveyed
- 831,076 trips

#### Travel purposes

- Work
- School
- Returning home
- Shopping
- Entertainment
- Daily life
- Business
- Other
-- Inferring urban activities from big data

Smart card data of Beijing in 2010
- Bus and metro ridings
- 10.9 million cards
- Over 100 million swaps
- Finishing identifying commuting trips

Crawled from Weibo
- China “Twitter”
- Check In

Taxi trajectories
- Microsoft Research Asia (MSRA)
- 30,000 taxis

Combined with POIs
- Over 100,000 categorized POIs
-- Activity-based travel model based on BEIJING100%

Increasing attention
- An alternative of conventional four-phase method

Based on one-day travel chain in the individual or group level
- E.g. home to work, shopping after work, backing home
All households

Having-car households

No-car households

Worker

Student

Others

Worker

Student

Others
## Trip chains of no-car workers

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<td>家-购物-家</td>
</tr>
<tr>
<td>5</td>
<td>HWSH</td>
<td>1.8</td>
<td>家-单位-购物-家</td>
</tr>
<tr>
<td>6</td>
<td>HOH</td>
<td>1.7</td>
<td>家-其他-家</td>
</tr>
<tr>
<td>7</td>
<td>HWHSH</td>
<td>0.8</td>
<td>家-单位-家-购物-家</td>
</tr>
<tr>
<td>8</td>
<td>HWHLH</td>
<td>0.7</td>
<td>家-单位-家-娱乐-家</td>
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<td>9</td>
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<td>0.7</td>
<td>家-娱乐-家</td>
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<td>10</td>
<td>HPWH</td>
<td>0.5</td>
<td>家-接送-单位-家</td>
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<td>11</td>
<td>HPWPH</td>
<td>0.5</td>
<td>家-接送-单位-接送-家</td>
</tr>
</tbody>
</table>

N = 29774, Sum of ratios = 82%

H=Home, W=Work, E=Eat, S=Shopping, P=Pick up, L=Entertainment, O=Others
BEIJING100%: Firms

630 thousand firms
- In 2010
- With 14.5 m job positions

Attributes
- Location
- Sector (all sectors 1-98 of China)
- Revenue
- Employee count

BEIJING100% also applicable for the meso BUDEM.
Microsimulation / microanalysis for macro policy evaluation

Policy (spatial or not)
→ Feedback and decision by individuals
→ Macro behavior and spatial heterogeneities

What could the plan response?
Case 1: Environmental evaluation

- Totals for all inventories from census report
- Allocating totals into parcels
  - Firms
  - Population
  - Human mobility
- Available for evaluating CO2 emission in the parcel level

Energy consumption per sqkm
Solid waste discharge per sqkm
SO2 discharge per sqkm
Case 2: Affordable housing location choice

Supply side
- Multi-criteria decision making using AHP
  - Market oriented factors
  - Institutional factors
- 110 sqkm available
- In the parcel scale

Demand side
- Synthetic population
- Quantified policy housing policies
- Contingency survey

Combining supply and demand sides
- Suggested locations, scales and construction order
- Policy evaluation
Other potential applications using BEIJING100%

- Small-scale urban redevelopment in the downtown area
- Metro line location choice
- Congestion zone setting
- Underground ring road
- Hazard influence evaluation
- Market-oriented applications
  - Shopping facility
Short-term forecast / scenario analysis

On going…

Extend human behavior in BEIJING 100%

Based on the macro/meso BUDEMs

Parcel-scale UrbanSim
  - Land develop, residential location choice, firm location choice

Activity-based travel model
  - Representative travel chains extracted from the 2010 survey
Conclusions

Three urban spatial development models in Beijing

A family of BUDEMs
- Applicable urban models
- Ranging from macro, meso to micro levels

Macro and meso BUDEMs
- Applications in strategic and master plans

Micro BUDEM
- BEIJING100%
- Applications in the detailed plan scale, e.g. plan scheme evaluation, policy evaluation and EIA
- More frequent application in plan practices

Demanding continuing efforts
Conclusions

Urban models in the era of “big data”

“Big data”
- GSM, GPS trajectories, smart card swaps, credit card, SNS, etc.
- Individual based
- Increasing availability

Opportunities or challenges
- Population synthesis v.s.
- inferring urban activities from bus/metro smart card data

The second requiem for large-scale urban models?
- Too much data, rather than limited computation capacity, in contrast to the first requiem in 1970s (Lee, 1973)

Urban modelling using “big data”? 
- Enriching data related with urban physical space, transportation, and human mobility/ activities
Thanks for your attention!

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