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

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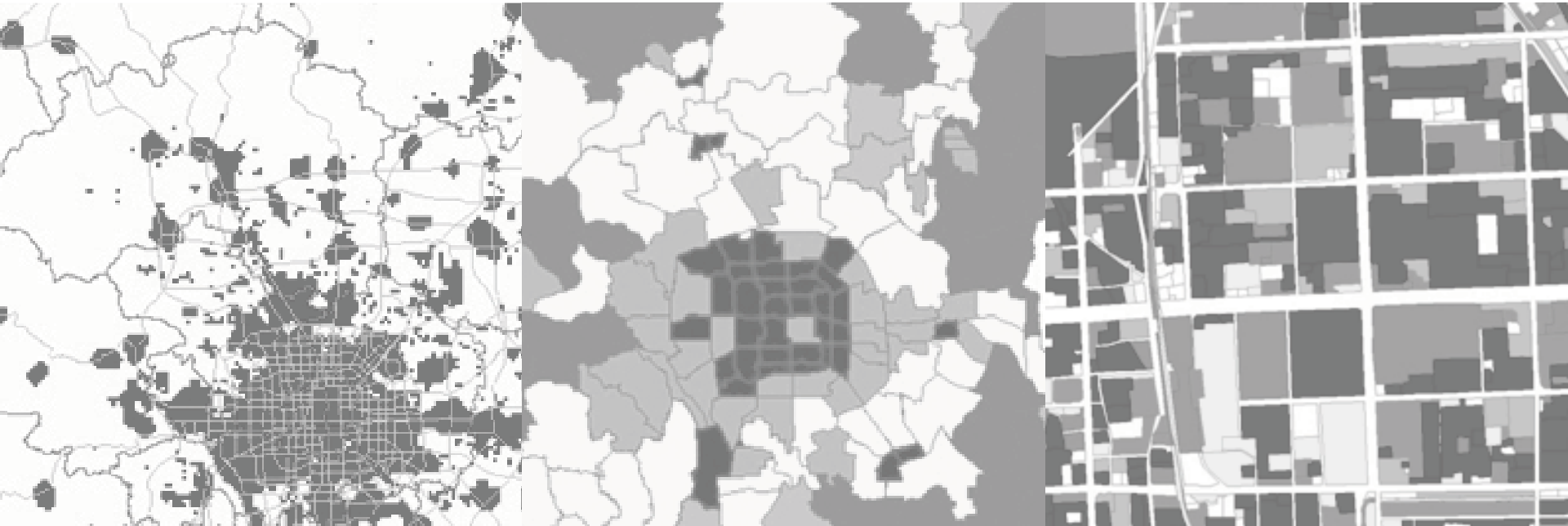
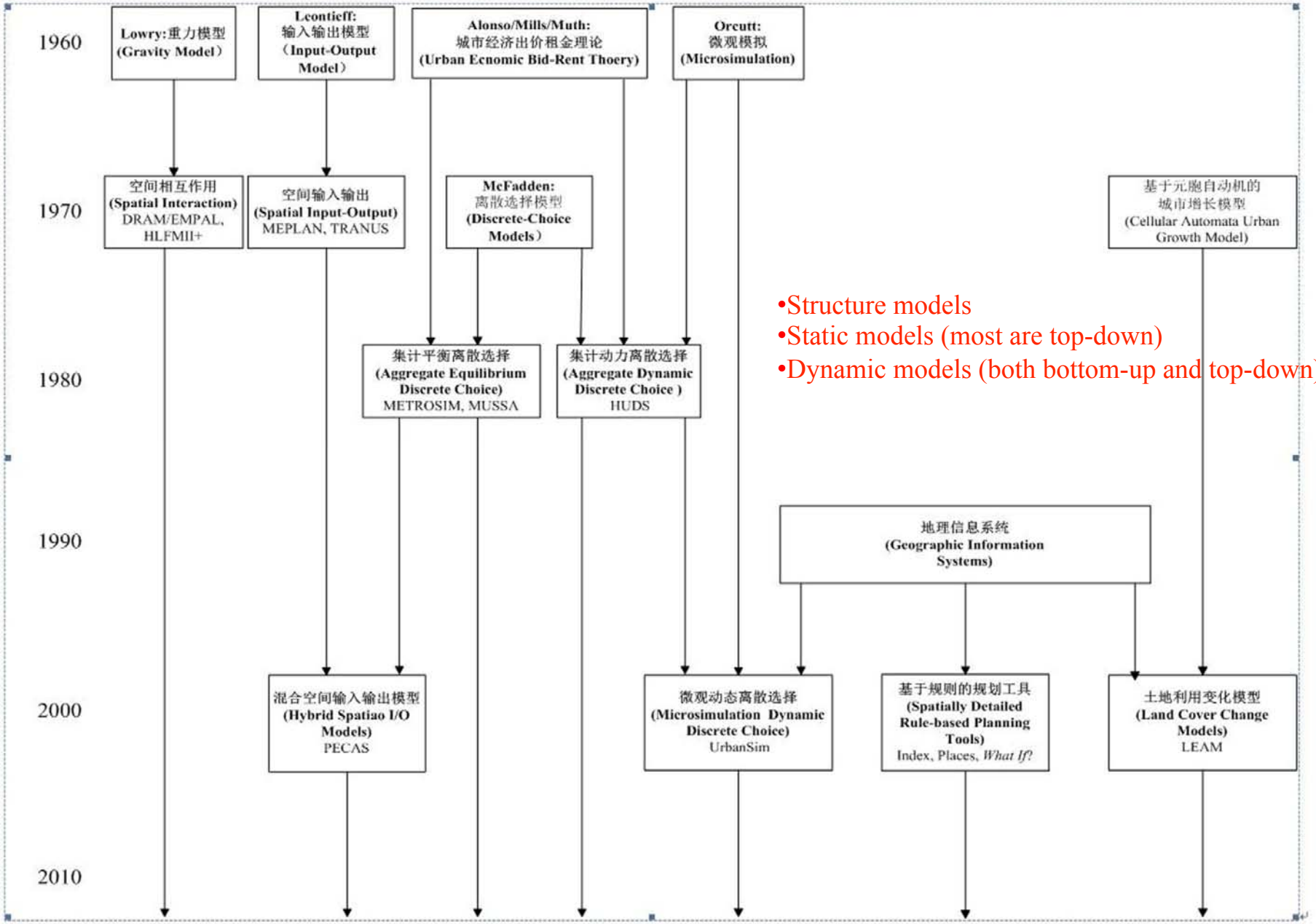


Applied urban modelling (AUM)

- This report falls into the pool of AUM
  - Rather than theoretical urban modelling
- Increasingly complex urban system
  - Residents, firms, buildings, parcels, policies, laws, standards and regulations
  - Integrated platform required for handling various aspects, giving thanks to the booming of IT
  - Man brain not applicable any more, of decision makers, planners even modelers
- City lab for testing policies
  - Evaluation
  - Forecasting
  - Scenario analysis
- Dozens of extensively applied approaches in existing researches
  - Various spatial scales
  - Structural, static and dynamic
  - Top-down vs. bottom-up



- Structure models
- Static models (most are top-down)
- Dynamic models (both bottom-up and top-down)

Applied urban modelling: a glance

Adapted from: Dynamic Microsimulation: UrbanSim, Webinar 5 of 8-part TMIP, Webinar series on land use forecasting methods.

Selected applied urban models

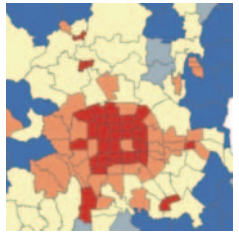
ID	NAME	CNTY	SCALE	AGE	DEVELOPER	APPROACH	T	LIT
1	POLIS	美国	小区	1960年代	旧金山湾区政府协会	空间相互作用、离散选择	静态	Association of Bay Area Governments. 2009
2	DRAM/ EMPAL	美国	小区	1970年代	Stephen H.Putman	空间相互作用、离散选择	静态平衡	Putman, 1995
3	**TRANUS**	委内瑞拉	小区	1982年	Modelistica	空间投入产出	动态平衡	Modelistica, 1995
4	**MEPLAN**	英国	小区	1984年	Marcial Echenique	空间投入产出	动态平衡	Echenique等, 1990
5	**TLUMIP**	美国	小区	1990年代	Tara Weidner	空间投入产出	动态平衡	Weidner等, 2007
6	**IRPUD**	德国	小区	1994年	Michael Wegener	离散选择	动态	Wegener, 1996
7	CUF	美国	DLU	1994年	John Landis	基于规则建模	动态	Landis, 1994
8	**DELTA**	英国	小区	1995年	David Simmonds Consultancy	离散选择	动态	Simmonds, 1996
9	Metrosim	美国	小区	1995年	Alex Anas	离散选择	动态平衡	Anas, 1994
10	UrbanSim	美国	**多尺度**	1996年	Paul Waddell	离散选择、微观模拟、基于个体建模	动态	Waddell, 2002

Selected applied urban models (-cont.)

ID	NAME	CNTY	SCALE	AGE	DEVELOPER	APPROACH	T	LIT
11	SLEUTH	美国	网格	1997年	Keith C. Clarke	元胞自动机	动态	Clark等, 1997
12	CUF-2	美国	网格	1998年	John Landis和 Ming Zhang	基于规则建模	动态	Landis和 Zhang, 1998ab
13	**ILUTE**	加拿大	**地块、居民、家庭**	2004年	Eric J. Miller	微观模拟、基于个体建模	动态	Miller等, 2004
14	**Relu-Tran**	美国	小区	2007年	Alex Anas	离散选择	动态平衡	Anas和Liu, 2007
15	**PECAS**	加拿大	小区	2005年	John Douglas Hunt和John E. Abraham	空间相互作用、空间投入产出	动态	Hunt和 Abraham, 2005
16	BUDEM	中国	500m网格	2009年	龙瀛	元胞自动机	动态	Long等, 2009
17	MUSSA II	智利	小区	1996年	Francisco Martinez	离散选择	动态平衡	, 1996
18	GeoSOS	中国	**多尺度**	2011年	黎夏	元胞自动机、基于个体建模	动态	Li等, 2011
19	Agent iCity	加拿大	**地块、居民、家庭**	2012年	Suzana Dragicevic	基于个体建模	动态	Jjumba和 Dragicevic , 2012
20	**BLUTI**	中国	小区	2012	张宇	离散选择	静态平衡	张宇等, 2012

BUDEM Families

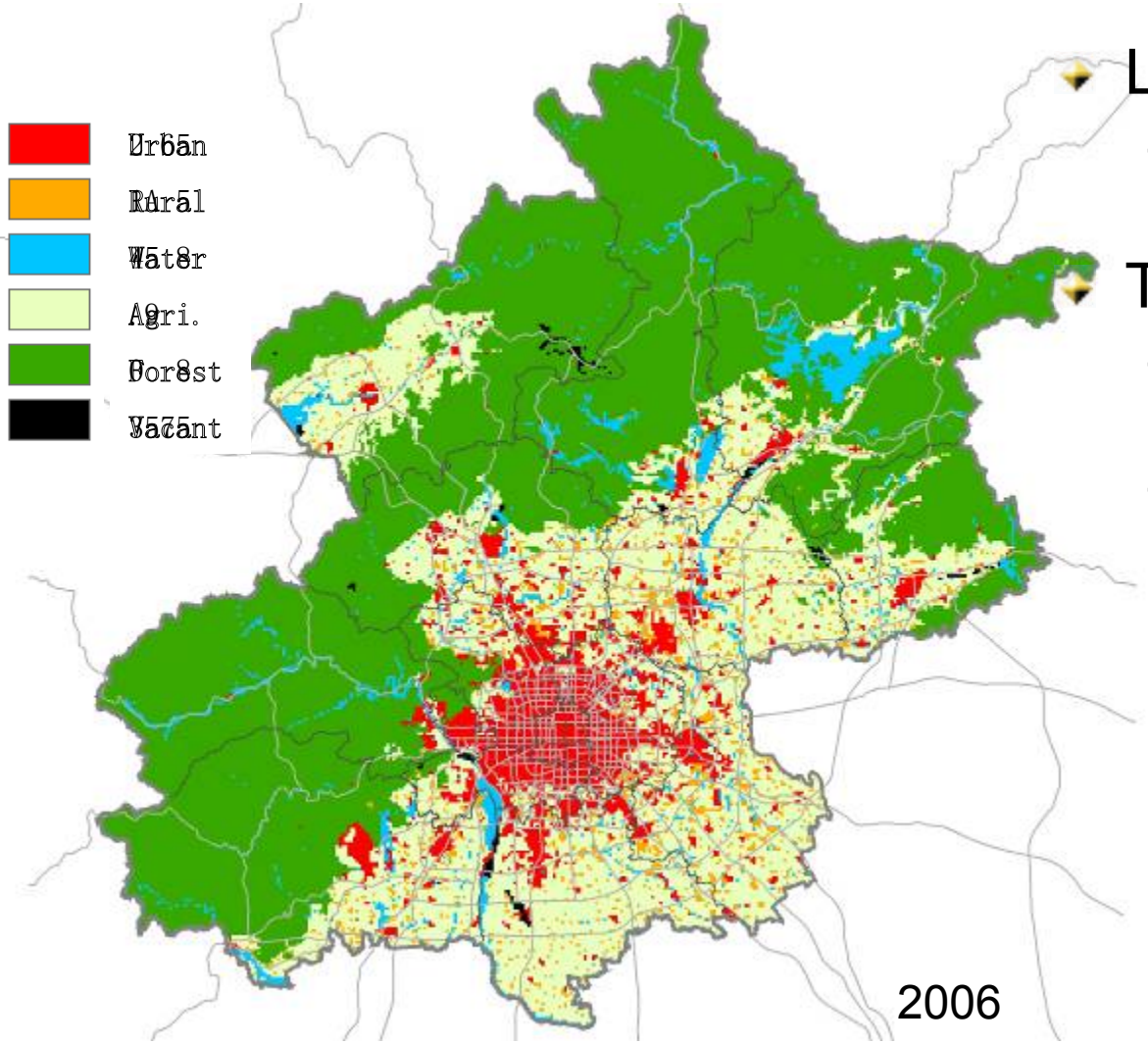
- Beijing Urban Spatial Development Model
  - Applied urban modelling
  - Launched in 2007 and in development
  - Supported by Beijing Institute of City Planning and Beijing Planning Commission
- Macro-level (city-scale)
  - Urban expansion analysis and simulation
  - Cellular automata, 500*500 m
- Meso-level (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



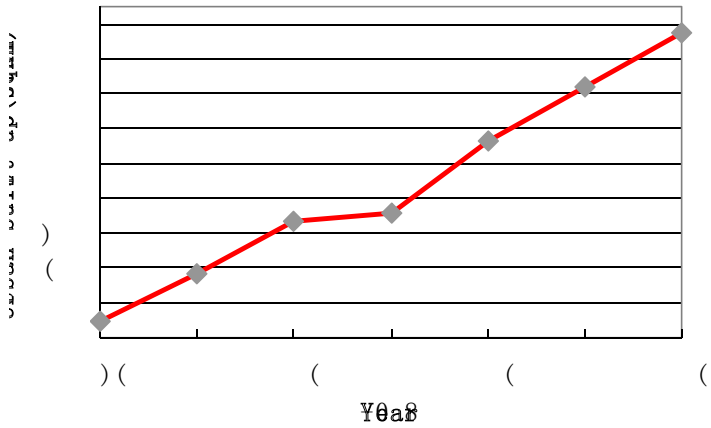
Study area of BUDEM

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

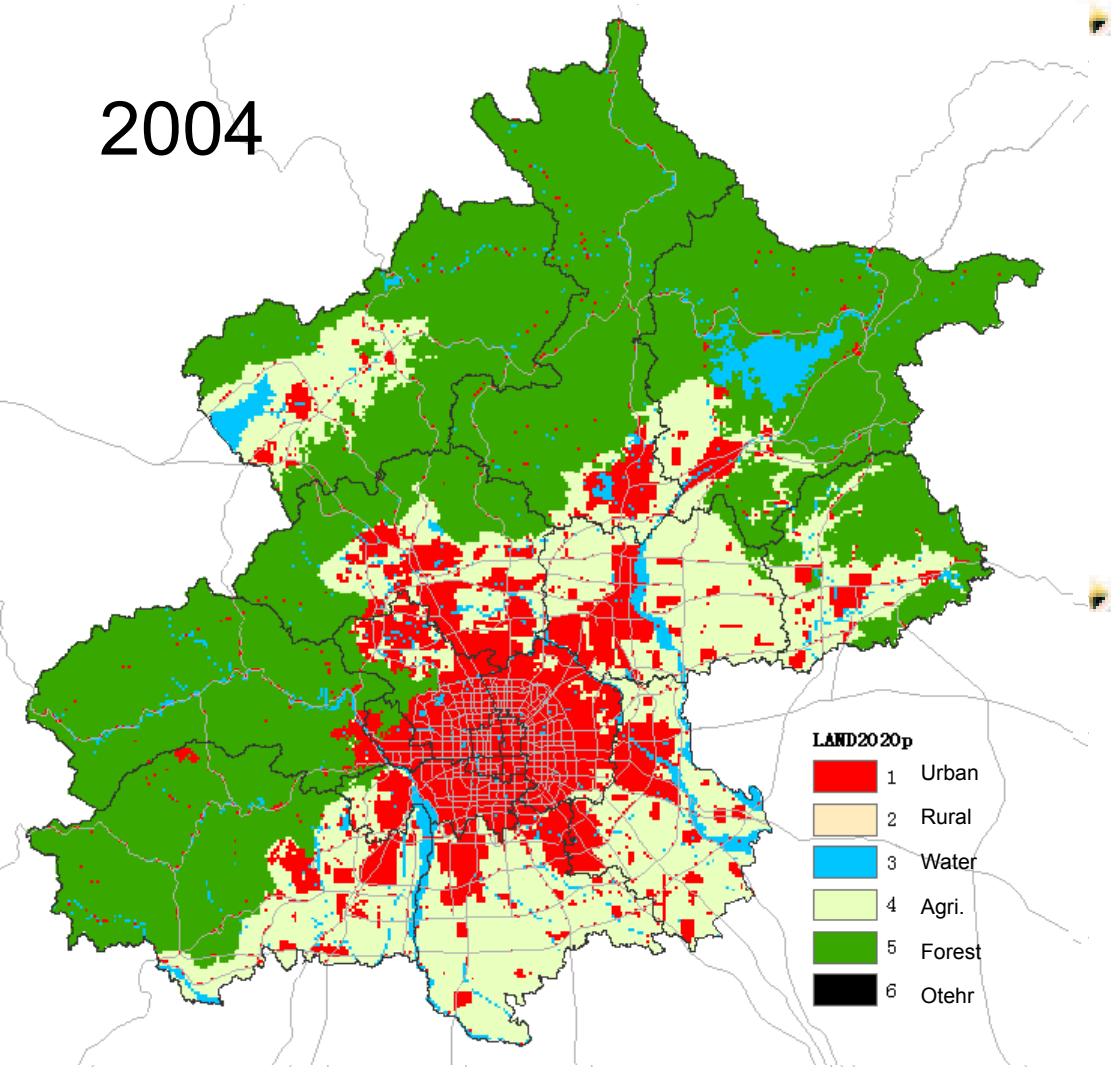
Rapid urban expansion in Beijing



- 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*

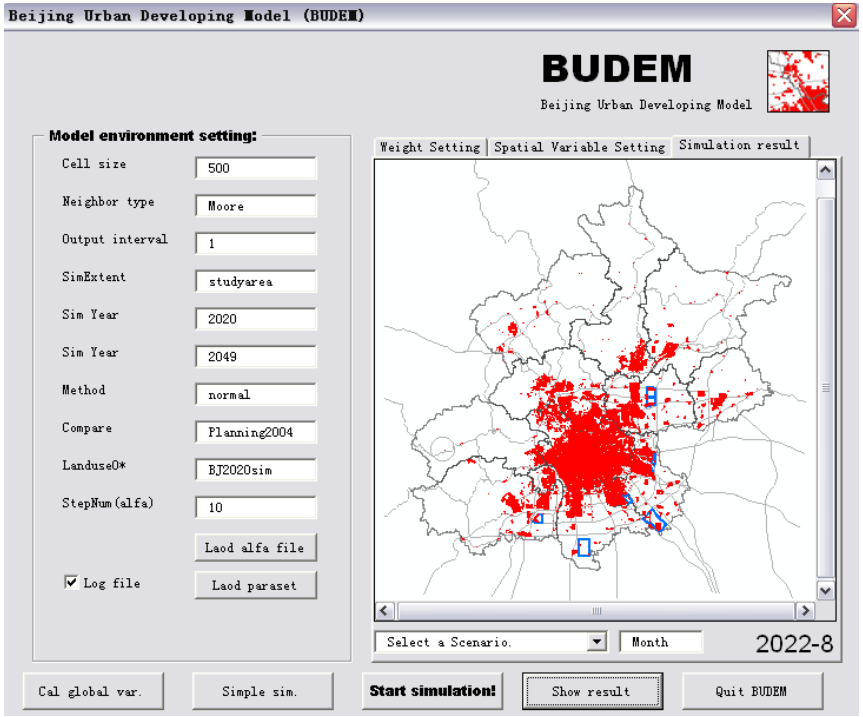
- Urban growth / expansion, redevelopment
- Urban form / urban structure
- Strong relationship between urban spatial organization and CO2 emission
  - Owens, 1987, Anderson et al., 1996; Banister et al., 1997

Macro BUDEM (2006-)

- Identifying driving force of urban expansion in various historical phases
- Evaluating the effectiveness of urban master plans in urban expansion
- Retrieving policies required to implement master plan for 2020
- Simulating urban growth scenarios with different policies set in 2049
- Planning support system for practical urban planning and management (various developing policies)

Long Y, Mao Q, Dang A, 2009, “Beijing urban development model: Urban growth analysis and simulation” *Tsinghua Science and Technology* 14(6) 787-794

An applied CA model



Approaches

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

Urban growth from undeveloped to developed only

CA settings:

- Cells
  - 500m * 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*3, rectangle, 8 adjacent cells
- Discrete Time
  - 1 iteration/step = 1 month

Driving forces of urban expansion

Select spatial factors using hedonic model

- Location
  - Minimum distance to hierachical 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*

$$V_{i,j}^{t+1} = f\left\{V_{i,j}^{t}, Global, Local\right\}$$

$$= \left\{V_{i,j}^{t}, LOCATION, GOVERNMENT, NEIGHBOR\right\}$$

$$= f\left\{\begin{array}{l} V_{i,j}^{t}, \\ d\_tam_{i,j}, d\_vcity_{i,j}, d\_city_{i,j}, d\_vtown_{i,j}, d\_town_{i,j}, \\ d\_river_{i,j}, r\_road_{i,j}, d\_bdtown_{i,j}, f\_rgn_{i,j}, \\ planning_{i,j}, con\_f_{i,j}, landresource_{i,j}, \\ neighbor^{t}_{i,j} \end{array}\right\}$$

Model calibration

Logistic regression result of various historical phases

Variable	B(2001-2006)	B(1996-2001)	B(1991-1996)	B(1986-1991)
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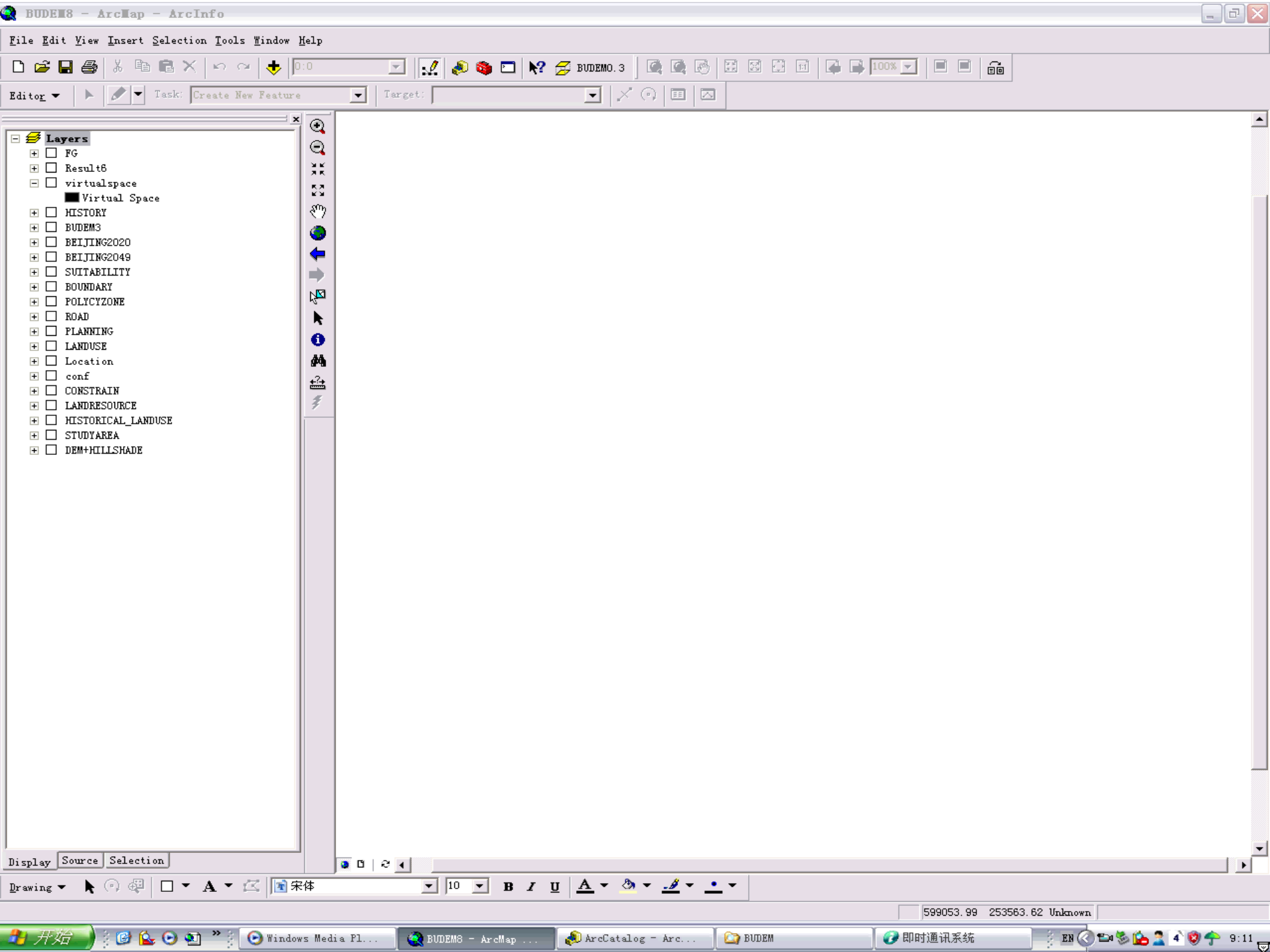
*Significant at 0.001 level

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

- 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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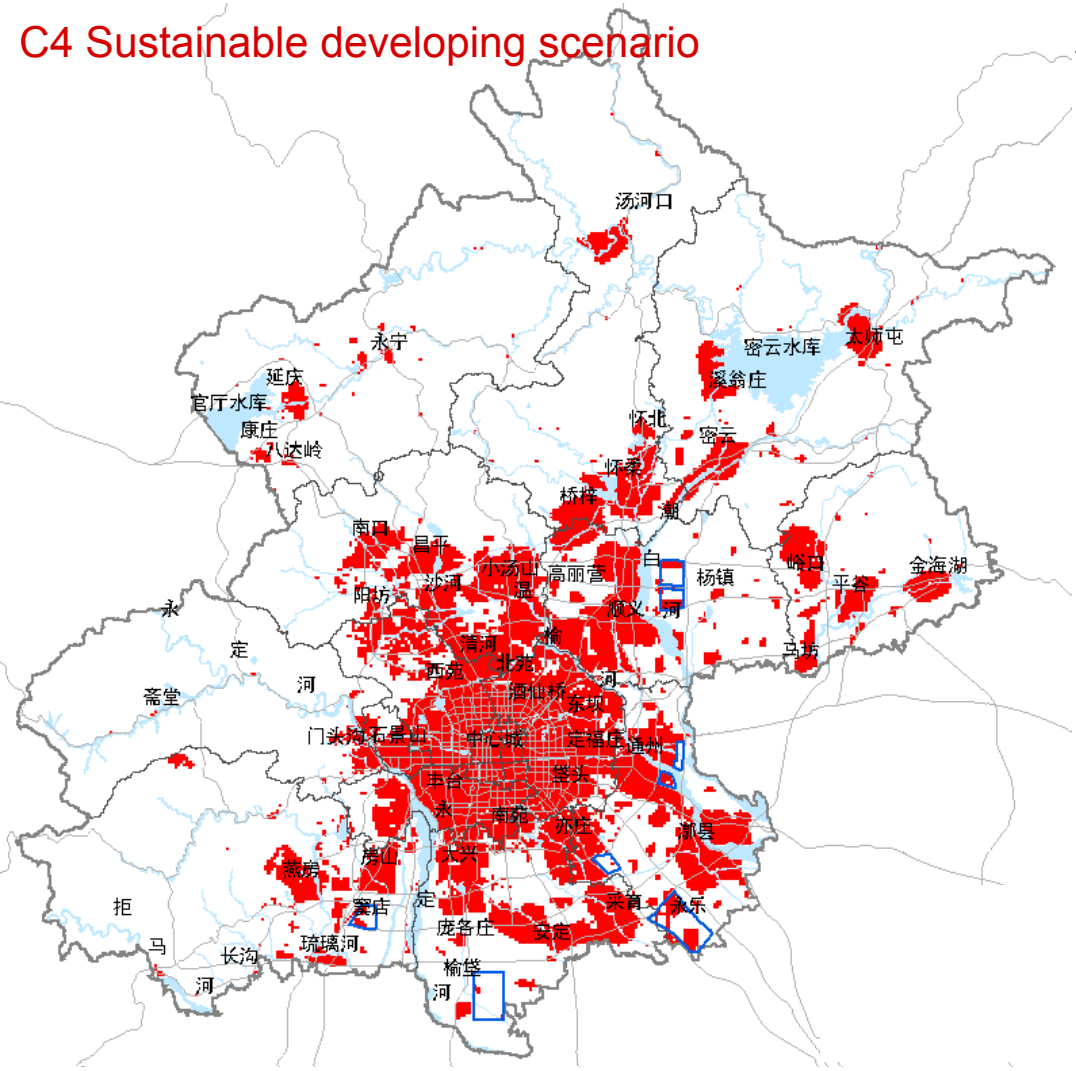
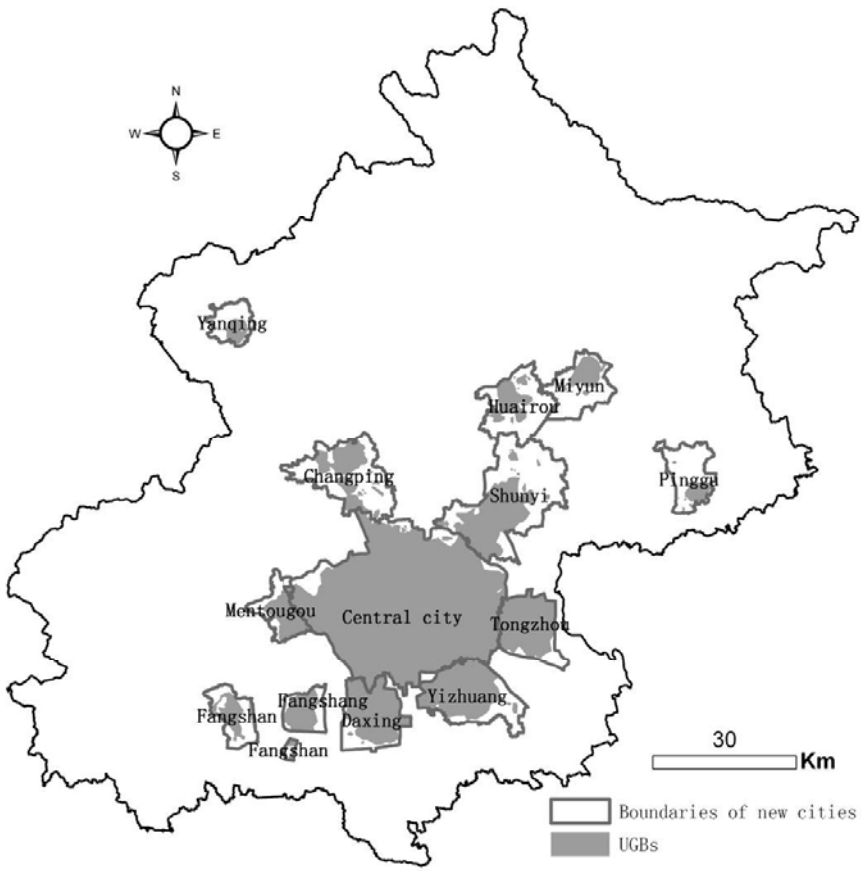
1 Urban expansion scenario analysis for 2049

C4 Sustainable developing scenario



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

Long Y, Han H, Lai S-K, Mao Q, 2012, "Urban growth boundaries of the Beijing Metropolitan Area: Comparison of simulation and artwork" *Cities* (In Press)

3 Urban planning implementation effectiveness

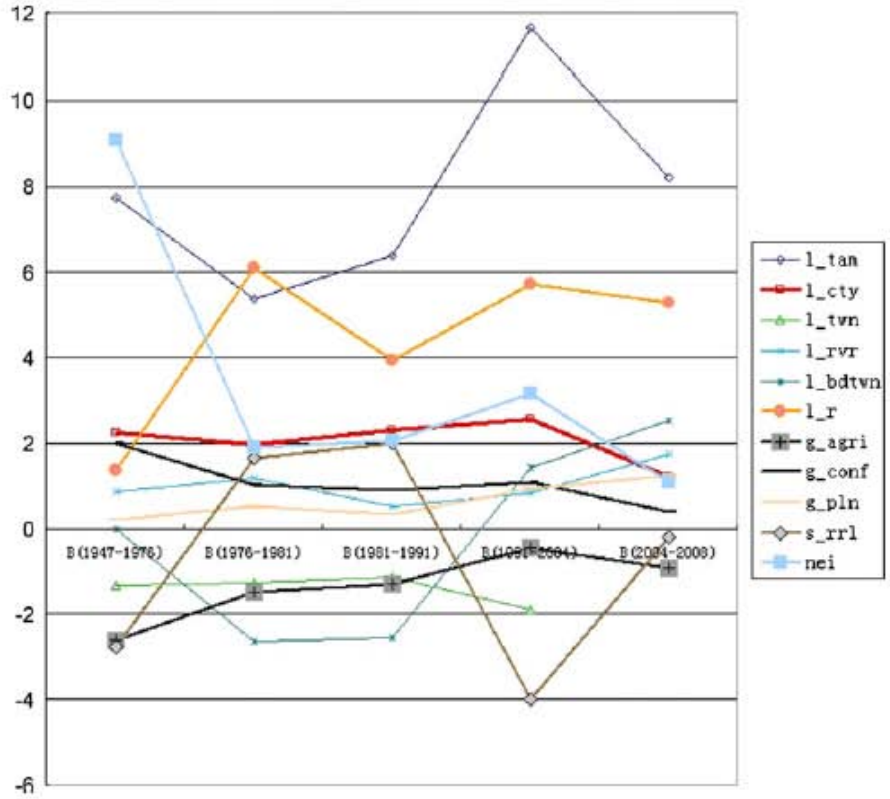


Fig. 3. Coefficients of all factors in various periods.

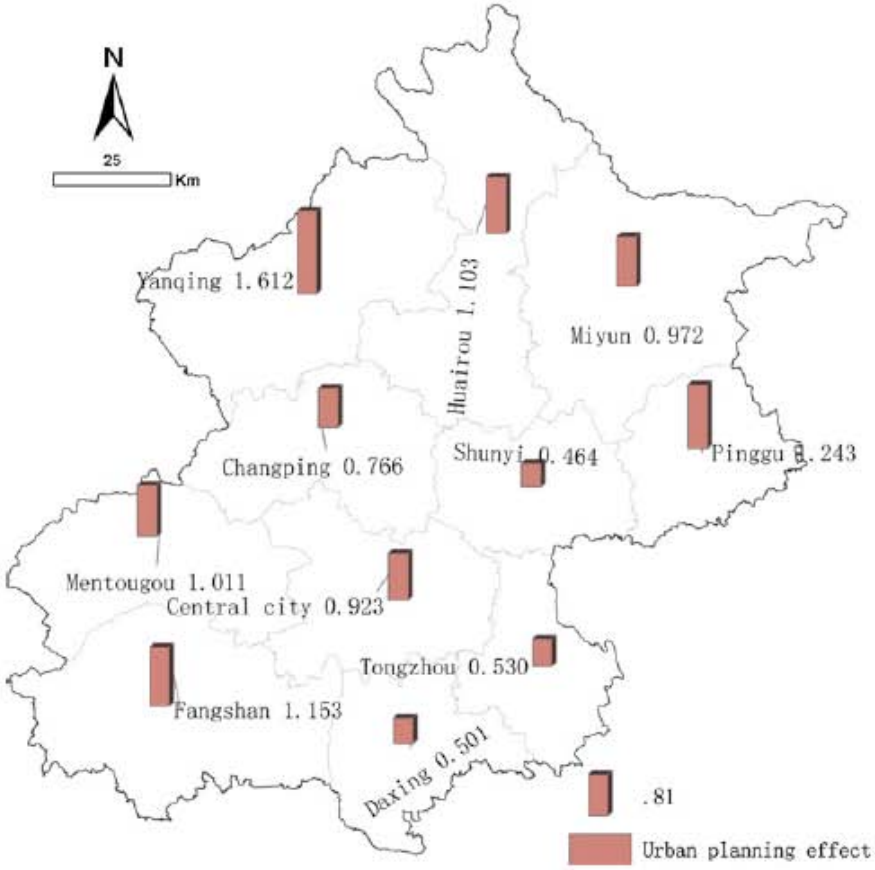


Fig. 4. Comparison of urban planning coefficients in various districts.

Long Y, Gu Y, Han H, 2012, "Spatiotemporal heterogeneity of urban planning implementation effectiveness: Evidence from five master plans of Beijing" *Landscape and Urban Planning* 108: 103-111.

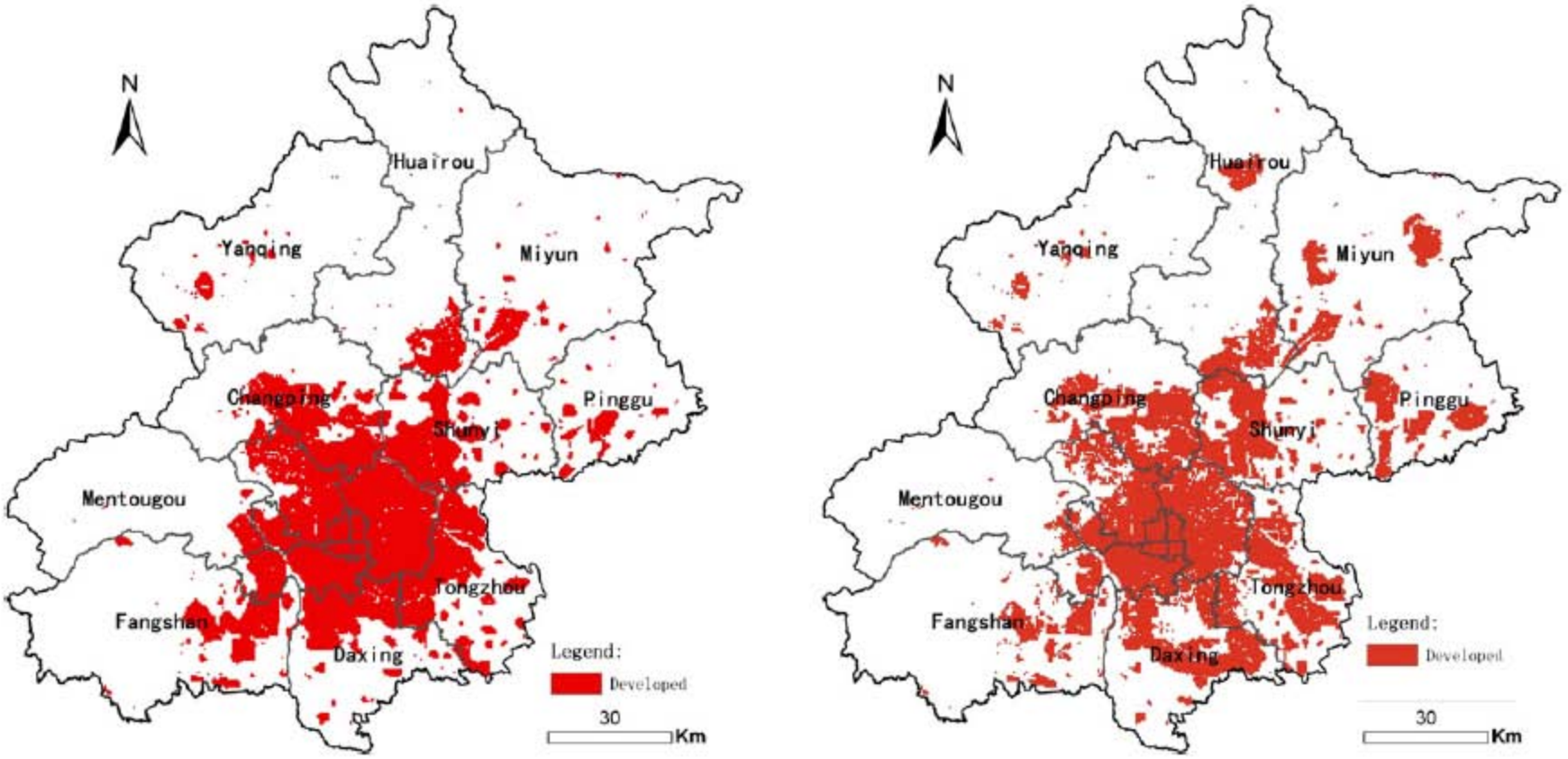
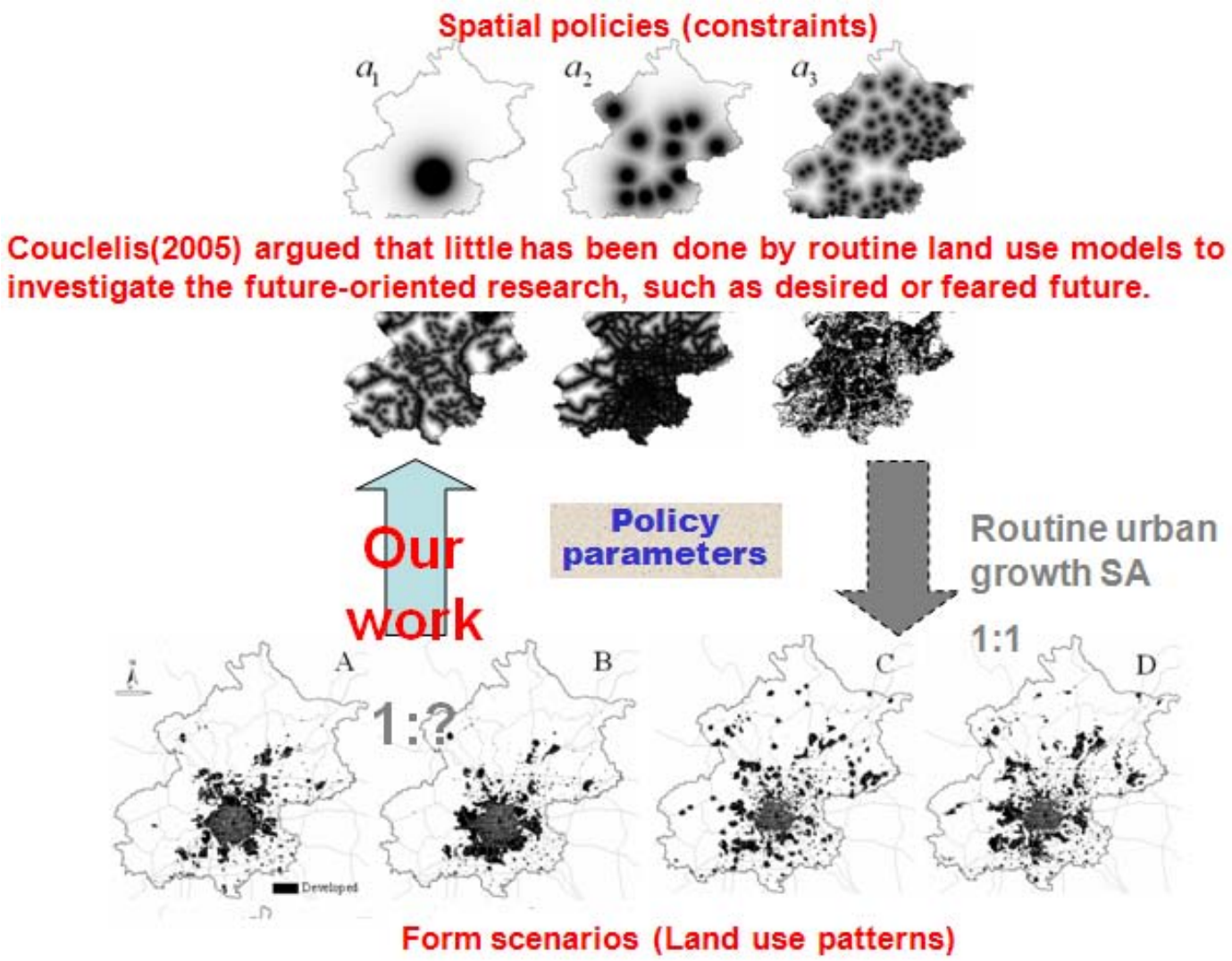


Fig. 5. Simulated urban forms by adjusting urban planning coefficient in BUDEM: the baseline scenario (left) and planning-strengthened scenario (right).

4 Identifying policy parameters for spatial plans



Long Y, Shen Z, Mao Q, 2012, “Retrieving spatial policy parameters from alternative plans using constrained cellular automata and regionalized sensitivity analysis” *Environment and Planning B: Planning and Design* 39(3) 586-604.

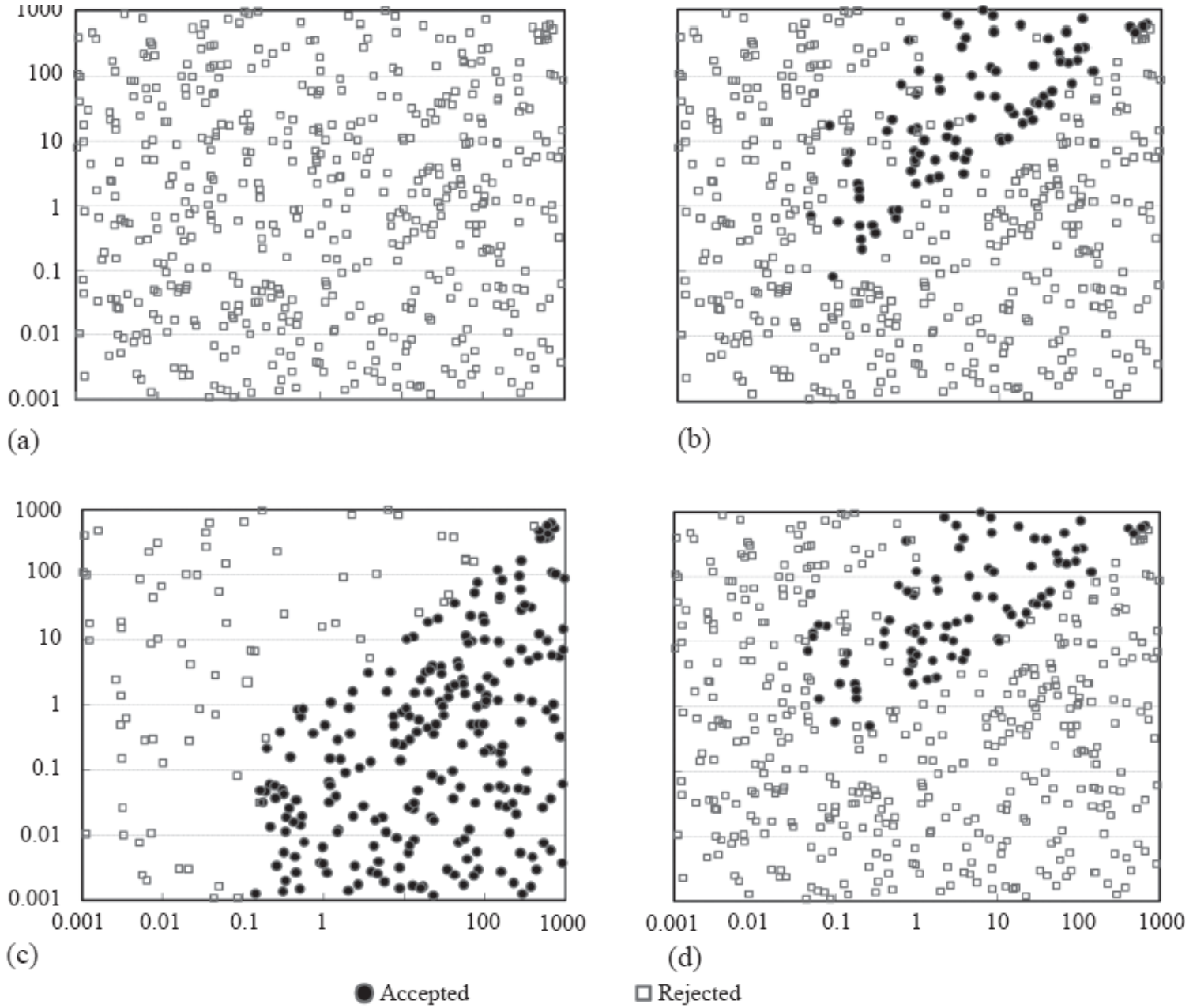
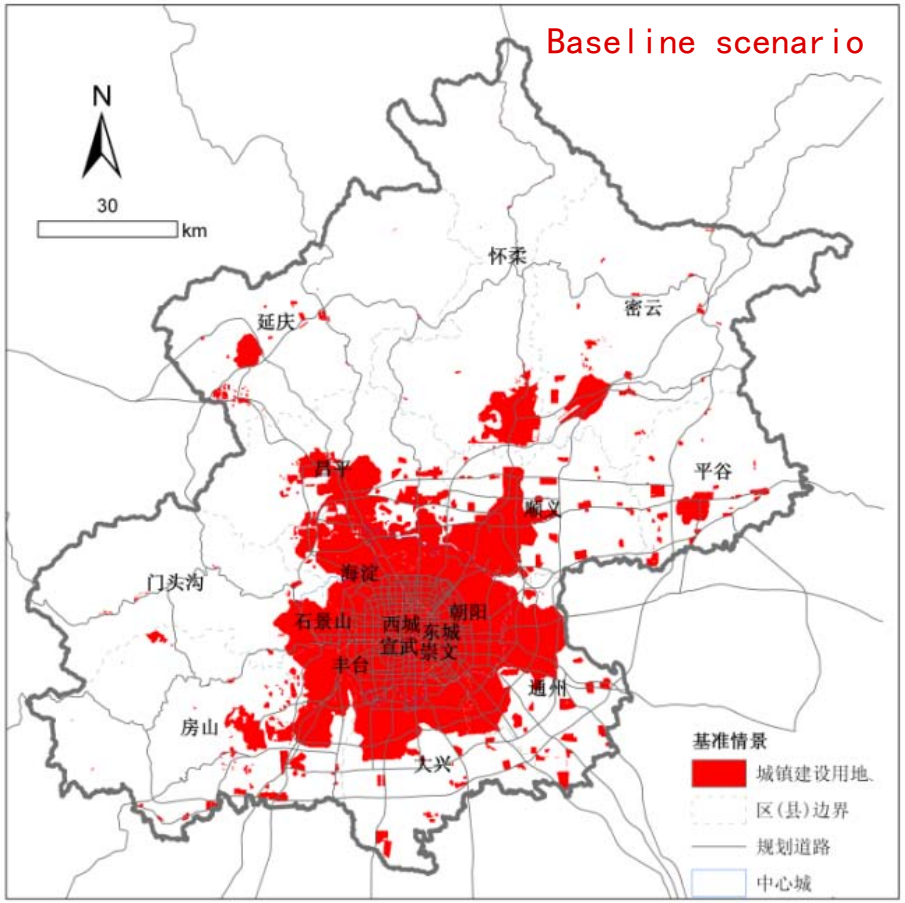
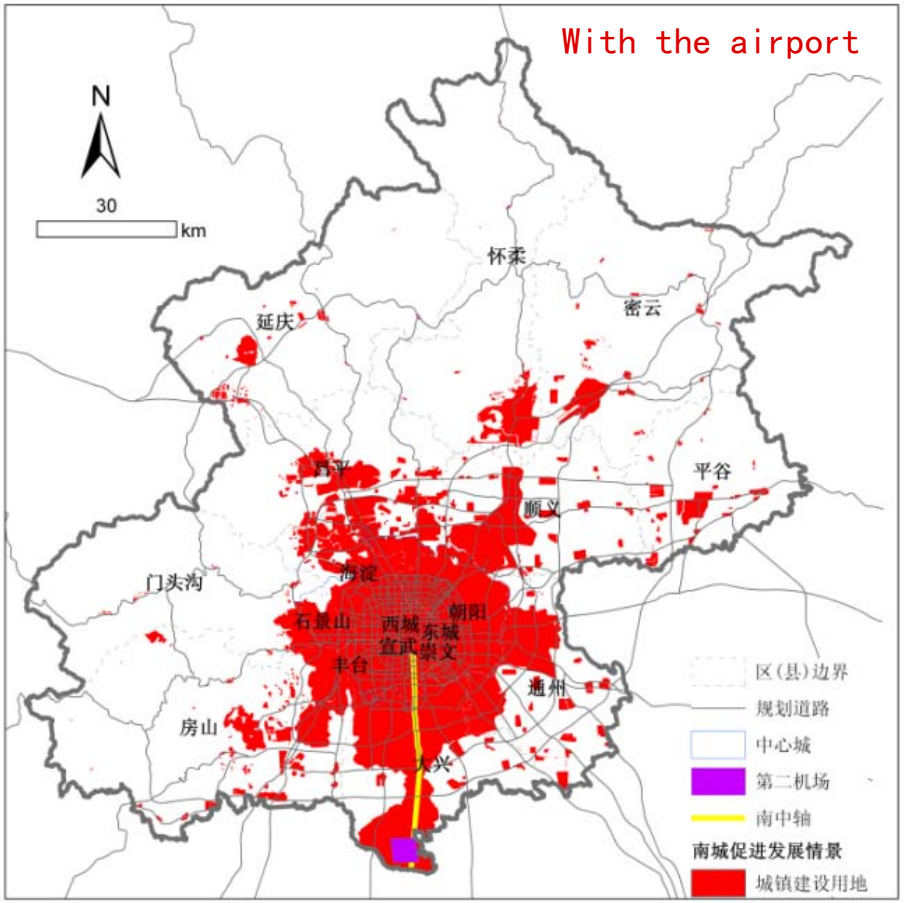


Figure 6. Scatter plots of policy parameters identified for two combined constraints in the virtual space, when the x axis is x_1, y axis is x_2 and 'accepted indicates' $\kappa \geqslant 80\%$. (a) Form 1, possibility of the urban form $P = 0\%$; (b) form 2, $P = 17.8\%$; (c) form 3, $P = 46.4\%$; (d)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

- 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





6 Extended to the Greater Beijing Area

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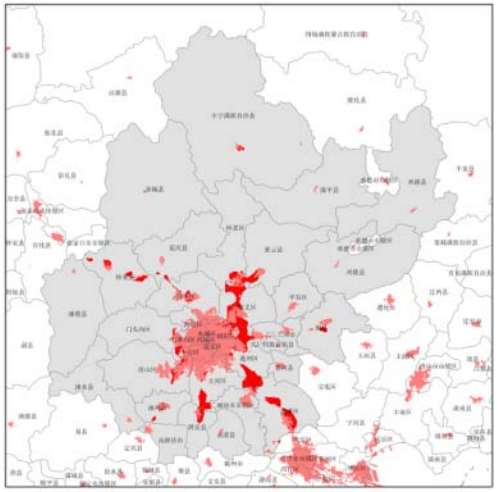
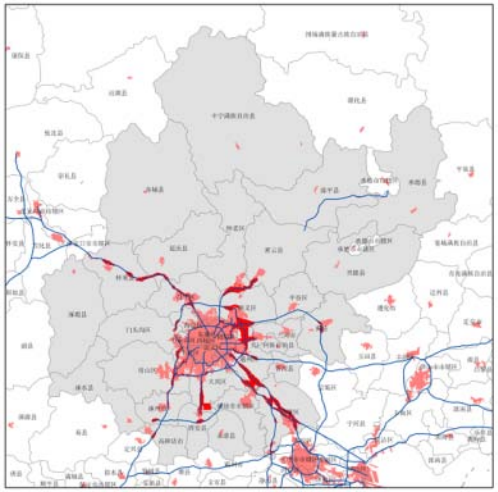
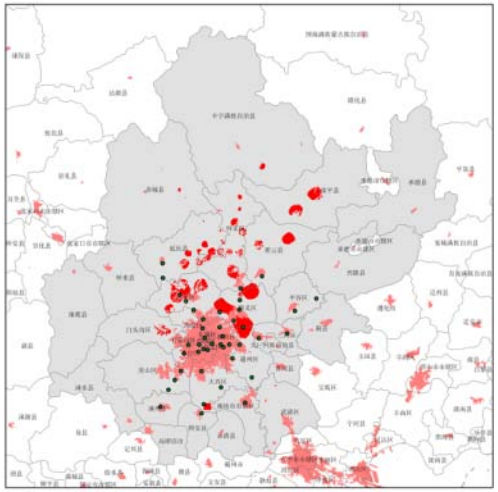
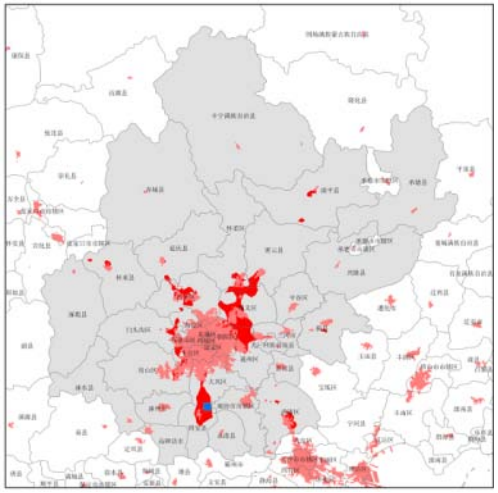


A2

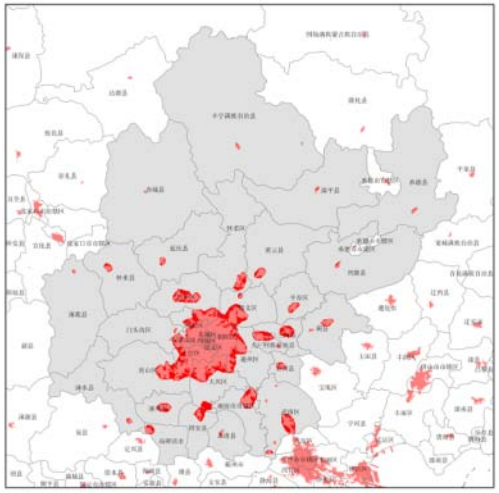


A3

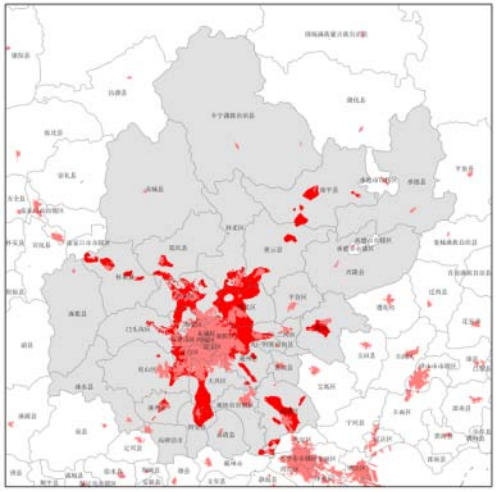




A4

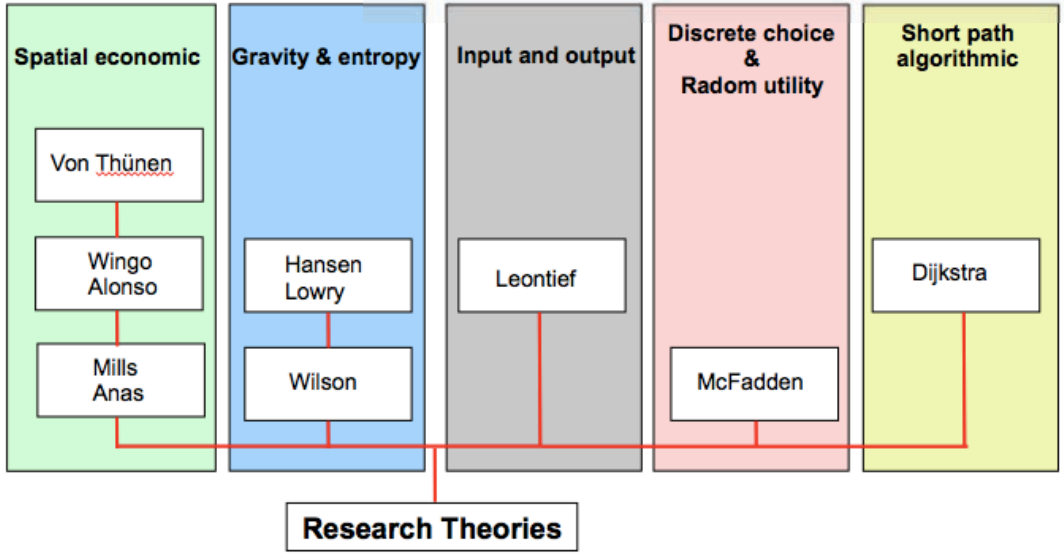


A5



A6

Meso BUDEM



Beijing Land-use and Transportation Integrated Model

- BLUTI v1.0
- Developed in 2009
- Long term forecast (2020)
- Based on Cube

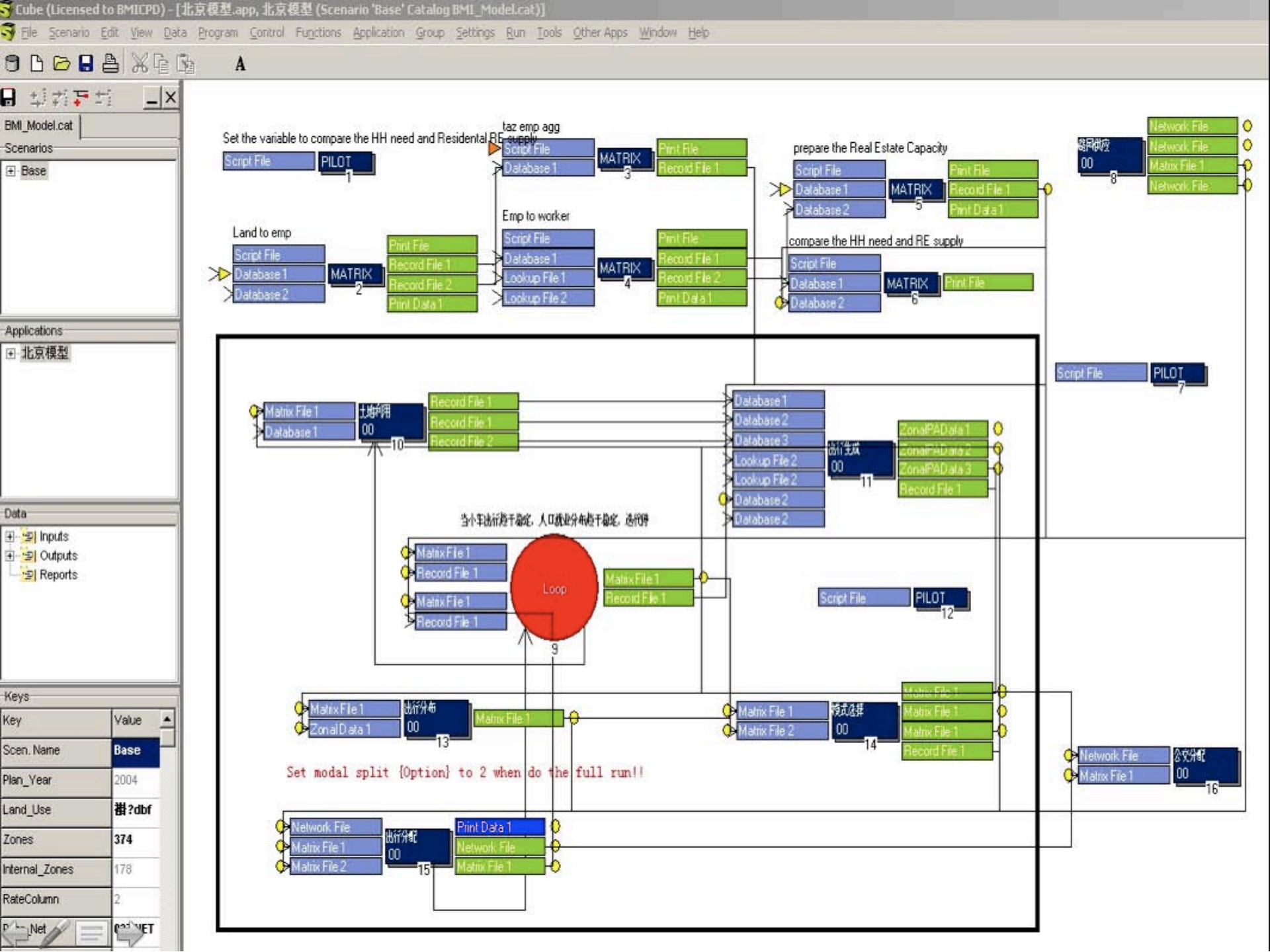
178 TAZs

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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Set the variable to compare the HH need and Residental RE supply
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Emp to worker
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compare the HH need and RE supply
Script File
PILOT
MATRIX
Print File
Record File 1
Database 1
Database 2
Lookup File 1
Lookup File 2
Print Data 1
Network File
Matrix File 1
Matrix File 2
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ZonalPAData 3
Loop
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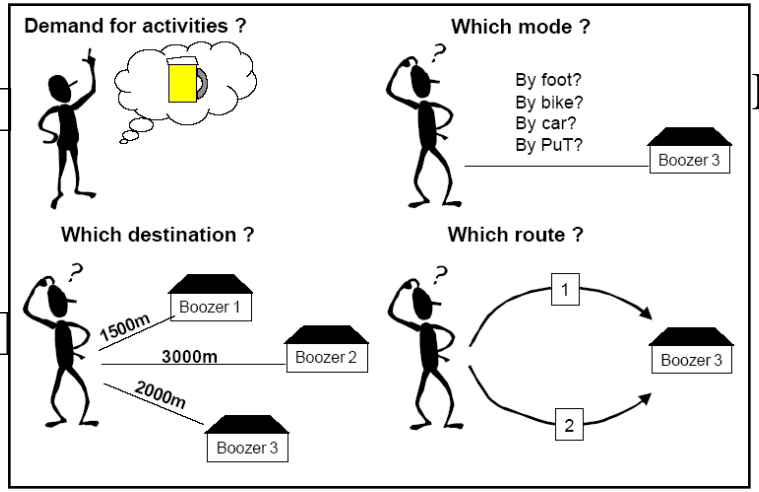
System structure of meso BUDEM□

Transportation sub-models

Trip Gen□



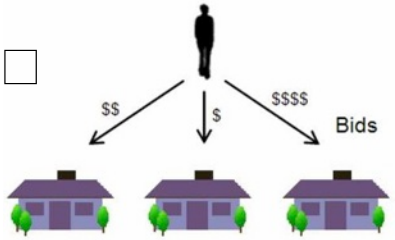
Mode Choice□

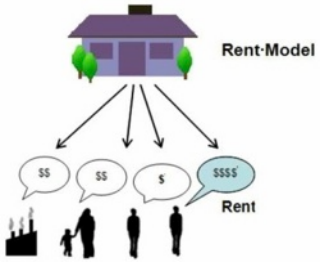
Trip Dist□

Traffic Ass□

Land use sub-models

Location Choice□



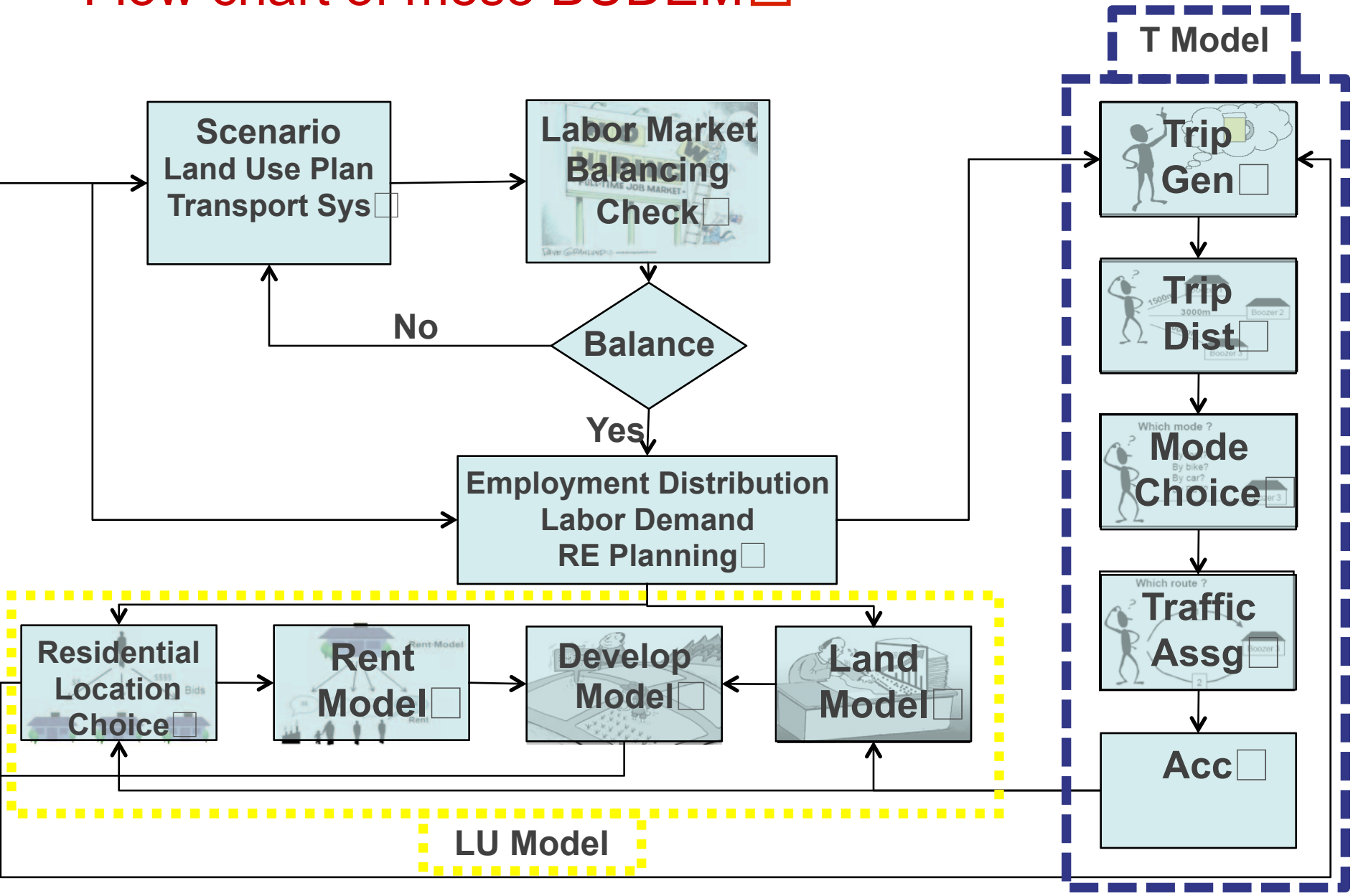


Rent Model

Land Auction

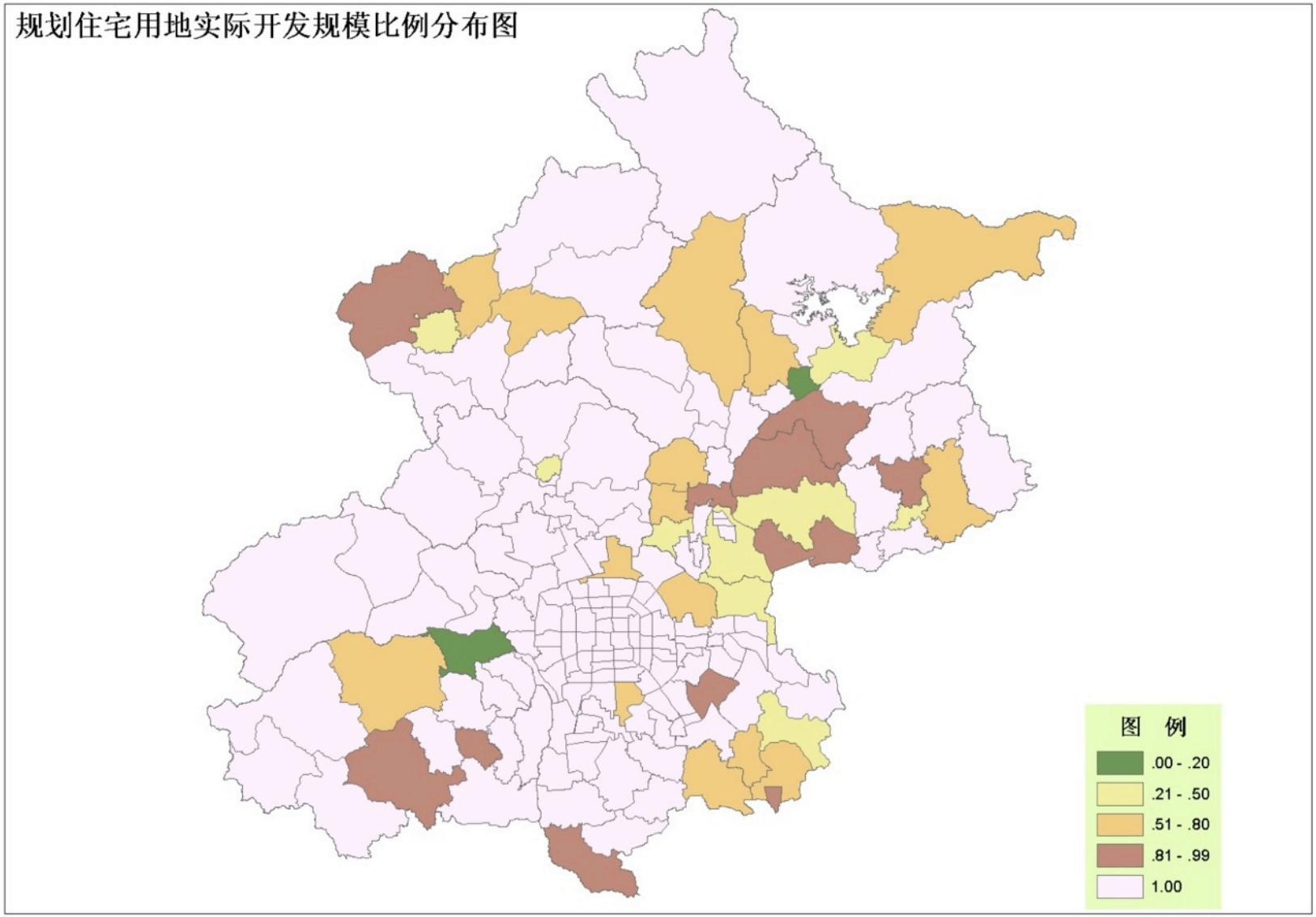
Develop Model

Flow chart of meso BUDEM□

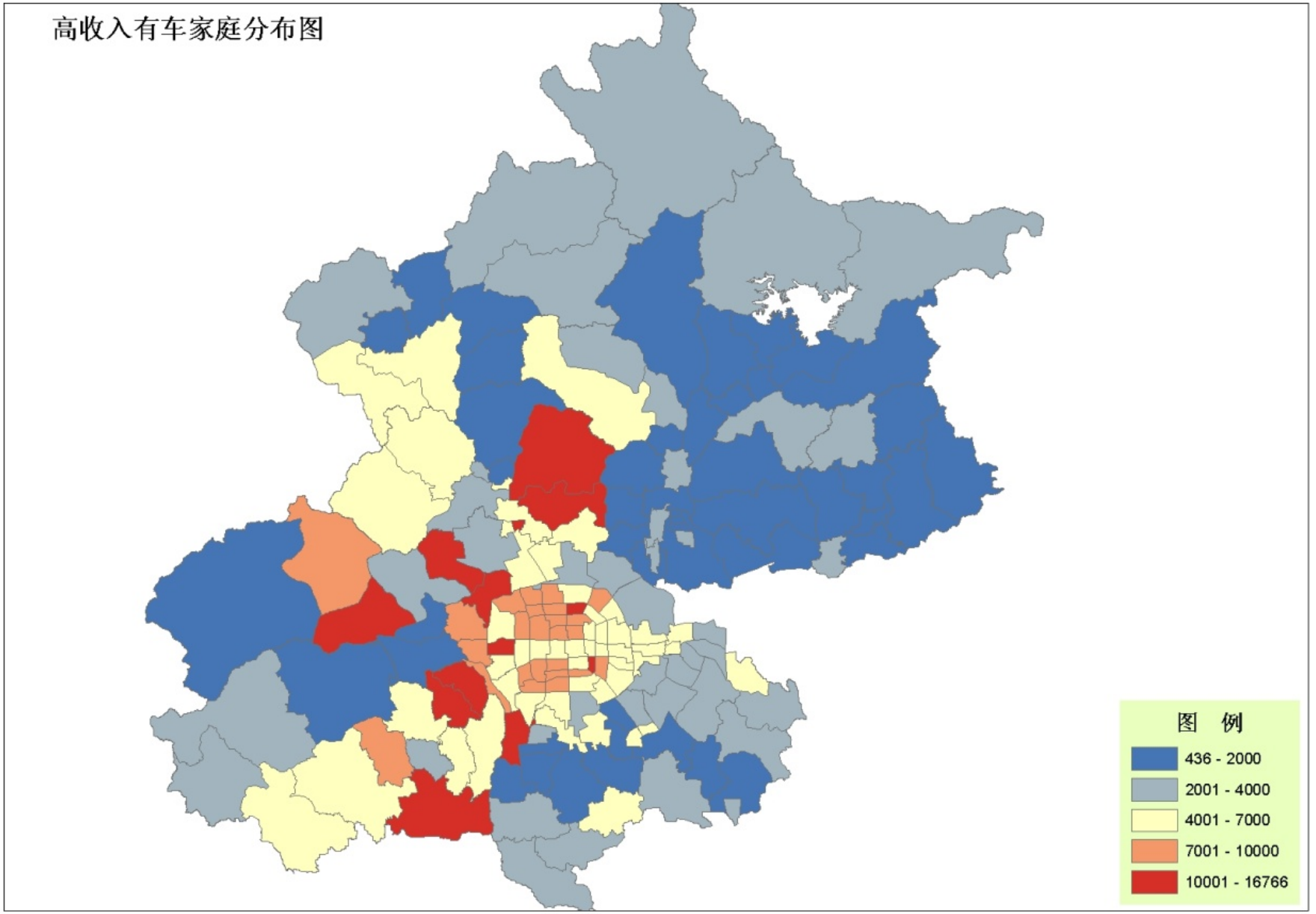


Applications:

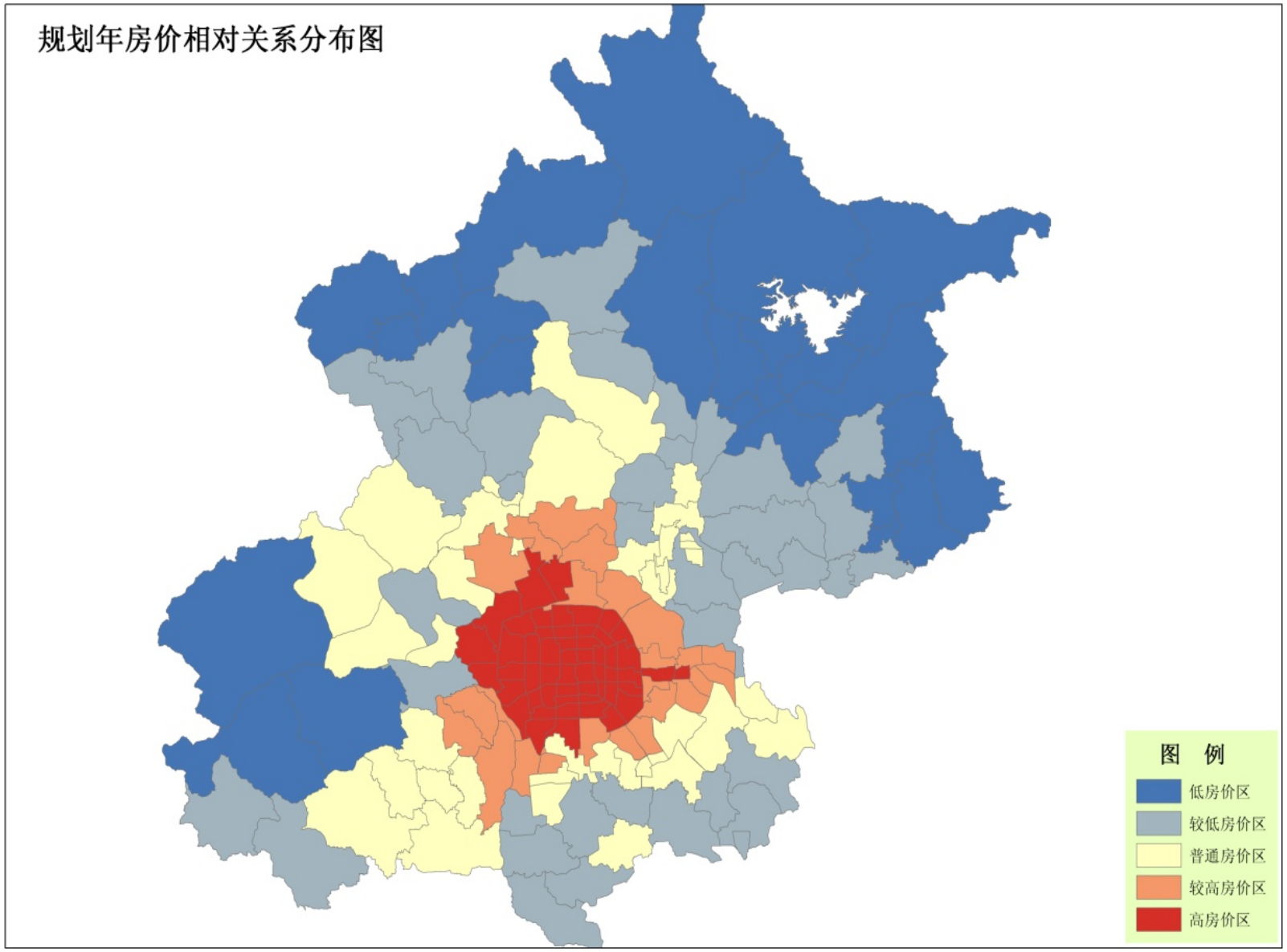
1 Residential land scale and distribution appraisal



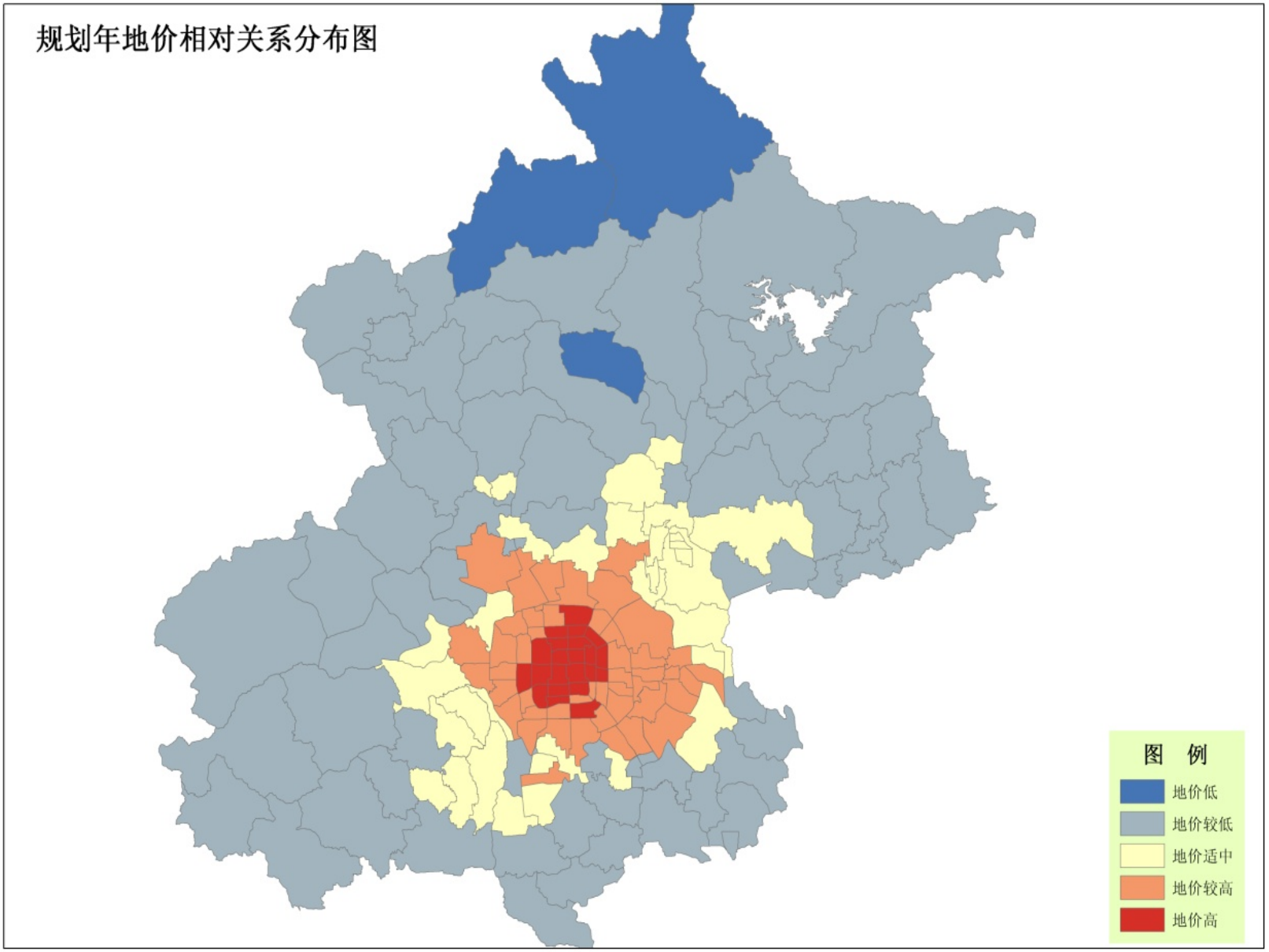
2 Forecasting the distribution of different household type



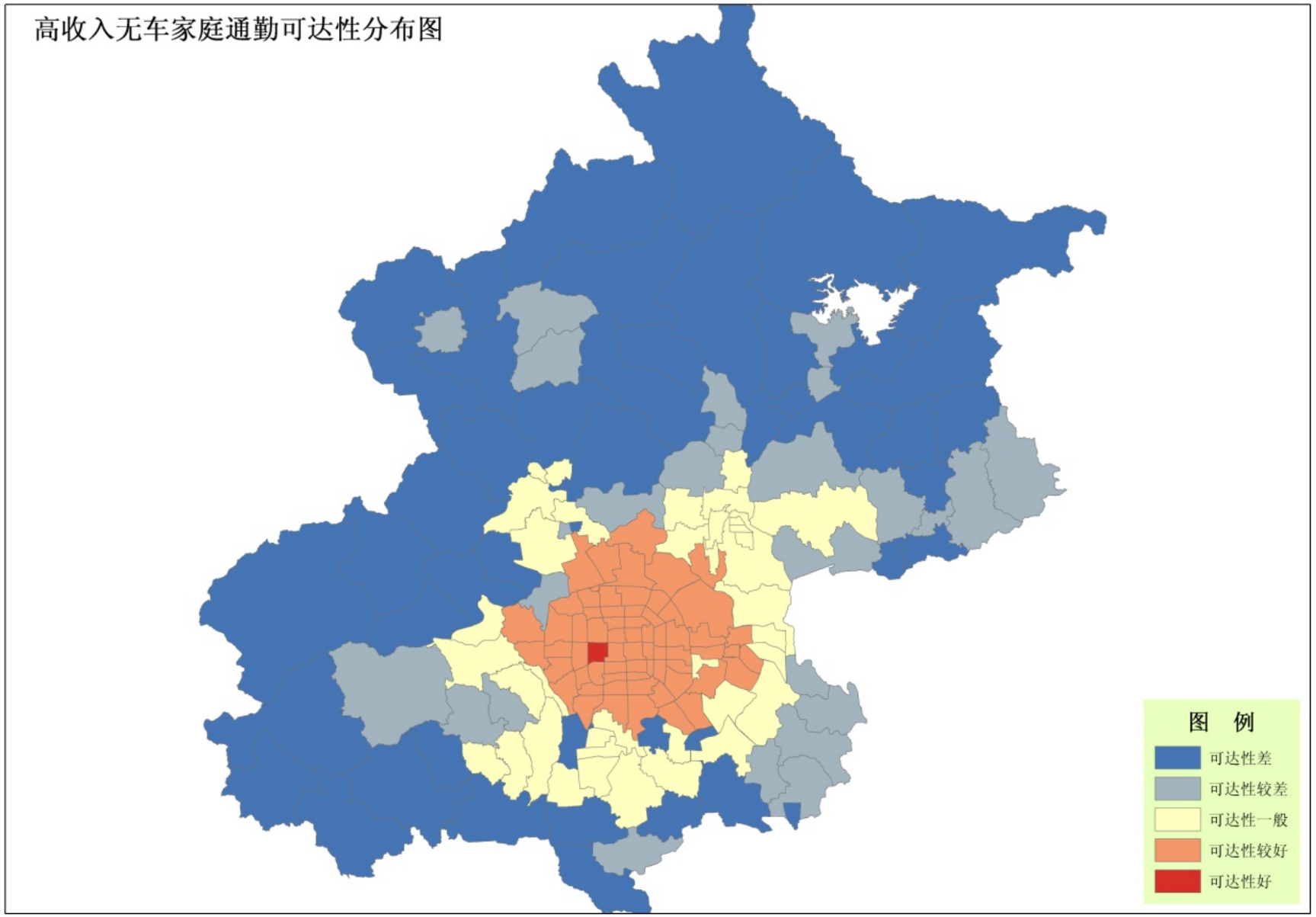
3 Forecasting the distribution of rent price



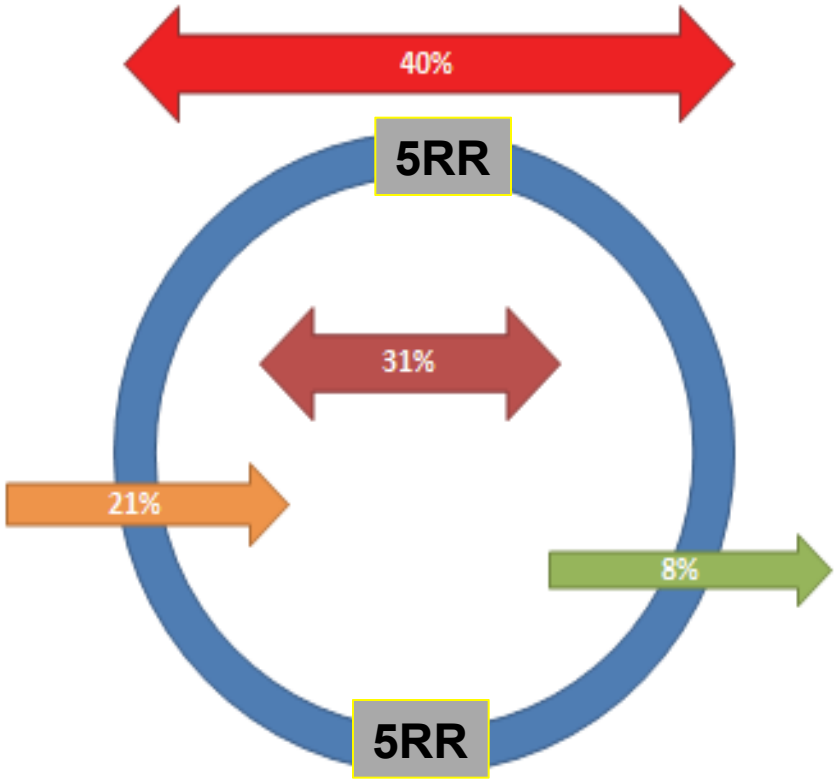
4 Forecasting the distribution of land price



5 Forecasting the accessibility

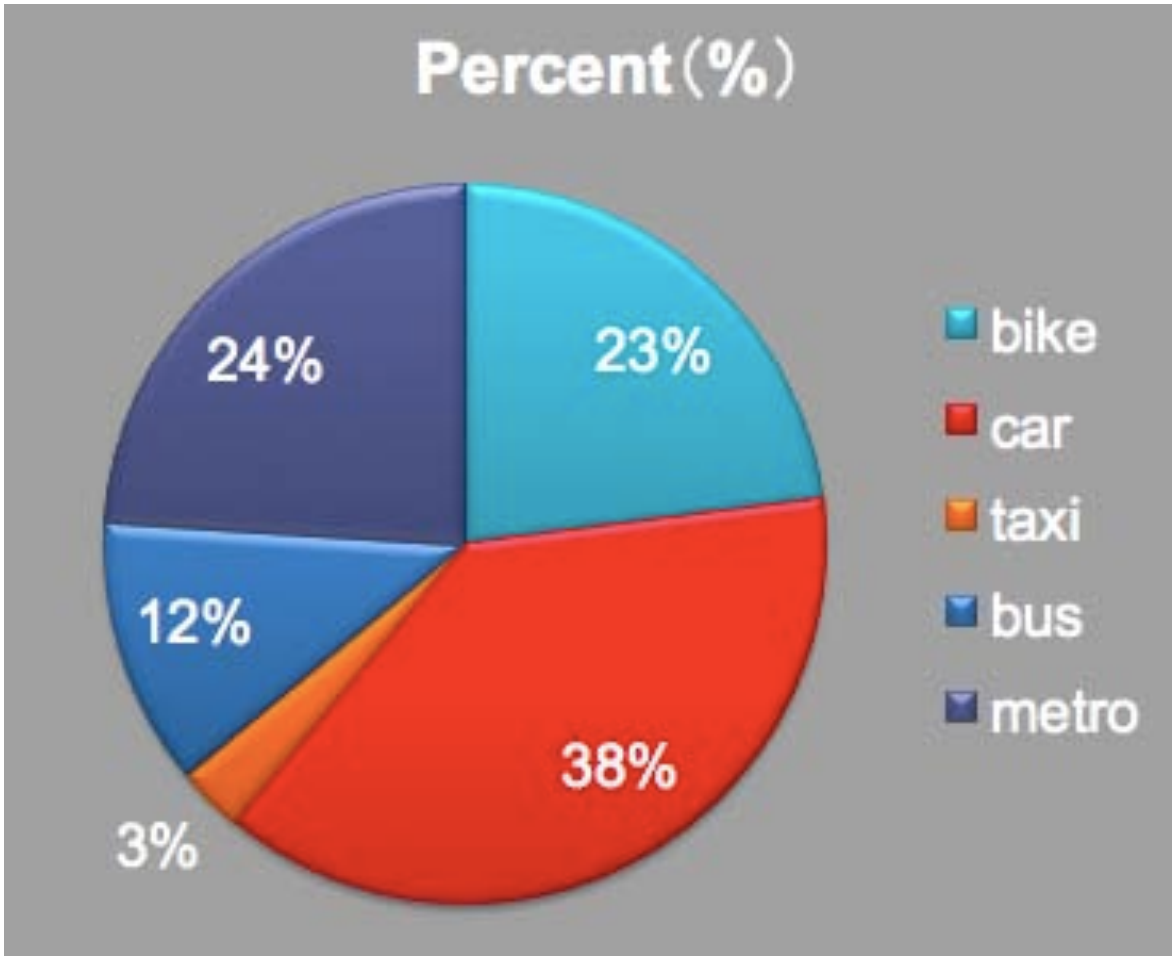


6 Forecasting the distribution of trips



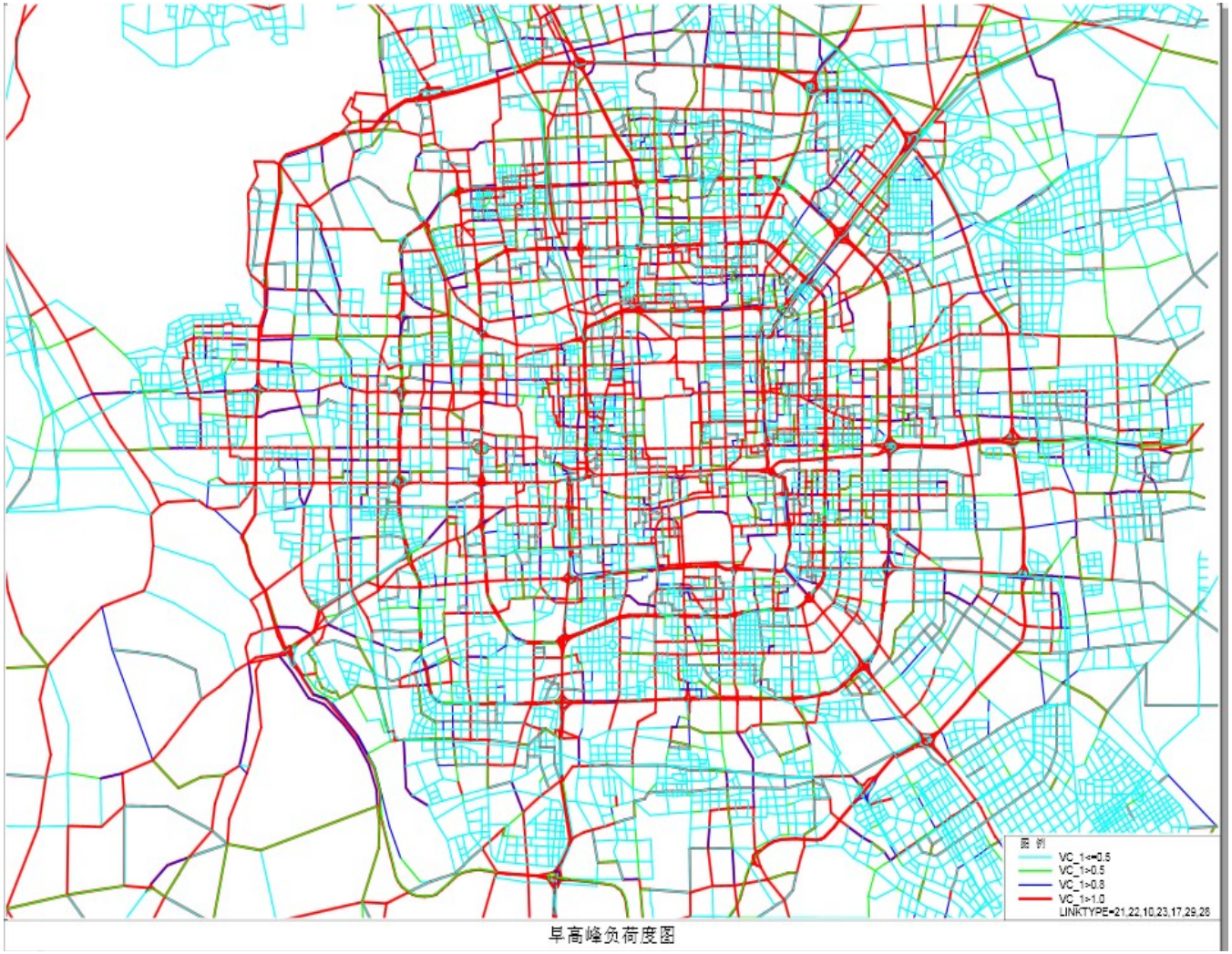
AM Peak-Hour PCU DISTRIBUTION

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

Balance

HH supply： 7.6 million

In upgrading to 1911 TAZs using UrbanSim, focusing on residential and firm location choice.

$$Probability = \beta_0 + \beta_1 LnPOTENTIAL + \beta_2 LnACC + \beta_3 LnD\_SUBWAY + \beta_4 U\_PRICE + \beta_5 O\_DUMMY$$

Micro BUDEM

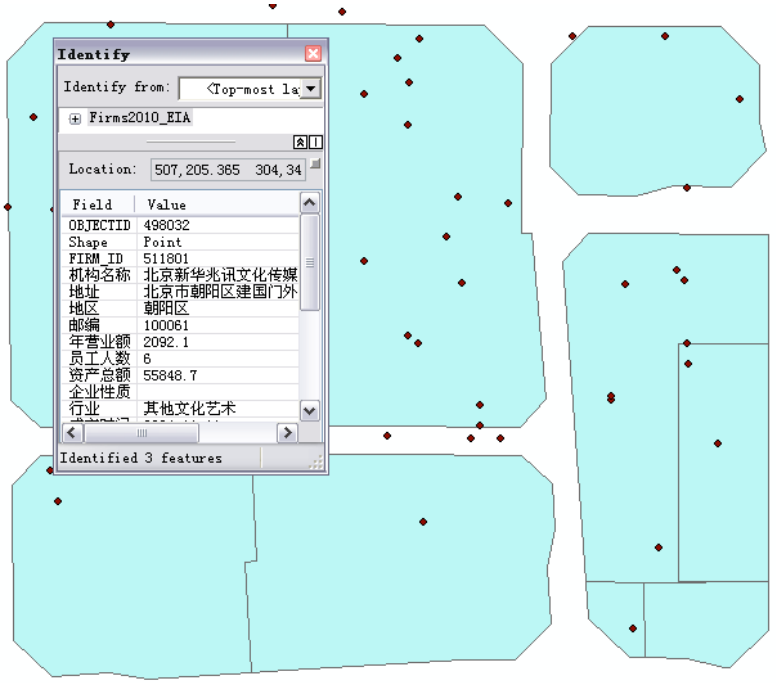
- An ongoing project (city lab for testing policies)
  - 2012-2014
  - Expected to continue during the academic visit to University of Cambridge from March 2013 to March 2014
- A fine-scale model for the whole Beijing Metropolitan Area
  - Rather than limited to typical neighborhoods based on questionnaire
  - 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

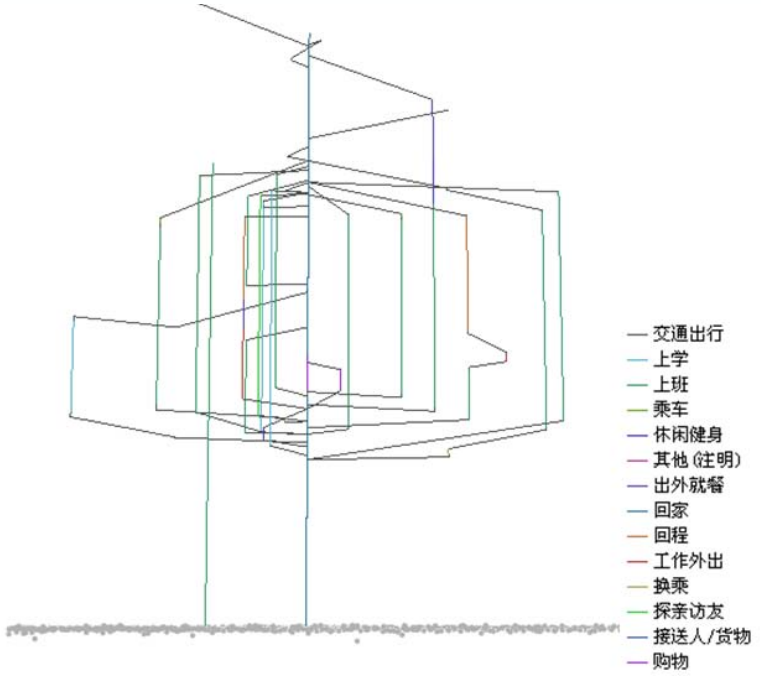
–Not applicable for long-term forecast or scenario analysis

BEIJING100%

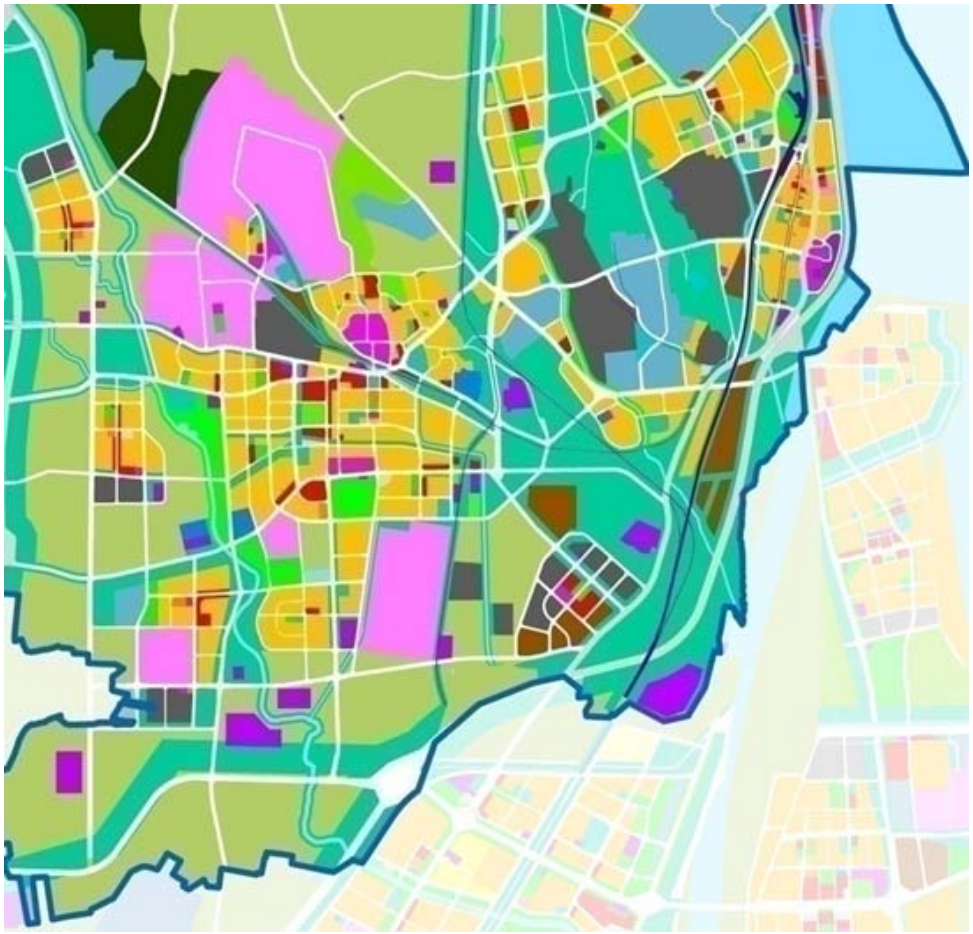
- Parcels
  - Existing, planned and permits
- Population
  - Households / residents
- Human mobility
  - Daily activities and all-modal trips
- Firms
  - All sectors
- Housing
  - Both commercial and affordable
  - Location, price and rent

BEIJING100% is 2010 based, and an extra evolution submodel will be proposed for short-term data synthesis in the near future.





BEIJING100%: 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

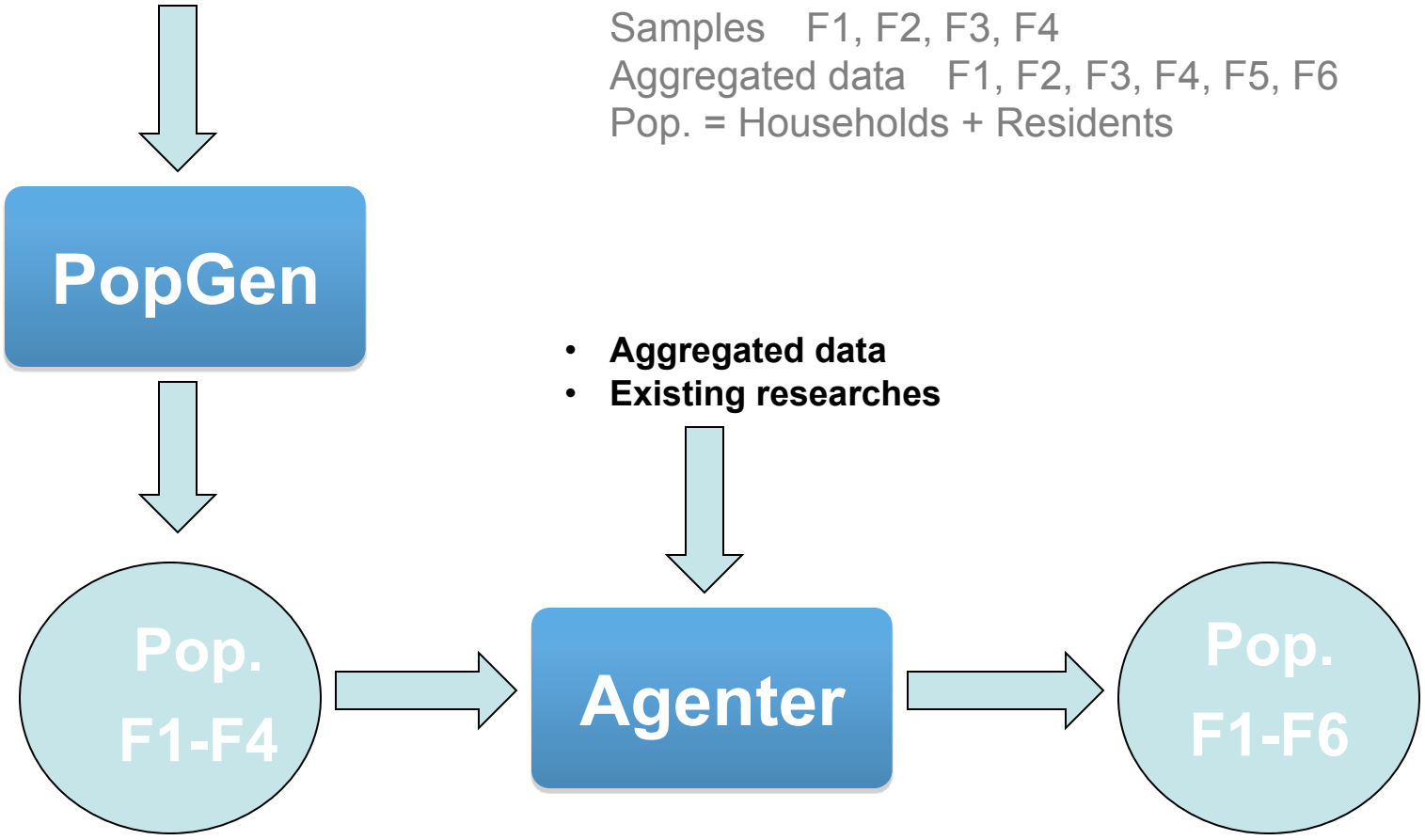
BEIJING100%: Population

- 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
    - Long Y, Shen Z, 2012, “Disaggregating heterogeneous agent attributes and location from aggregated data, small-scale surveys and empirical researches” Computers, Environment and Urban Systems (Revision under review)

BEIJING100%: Population

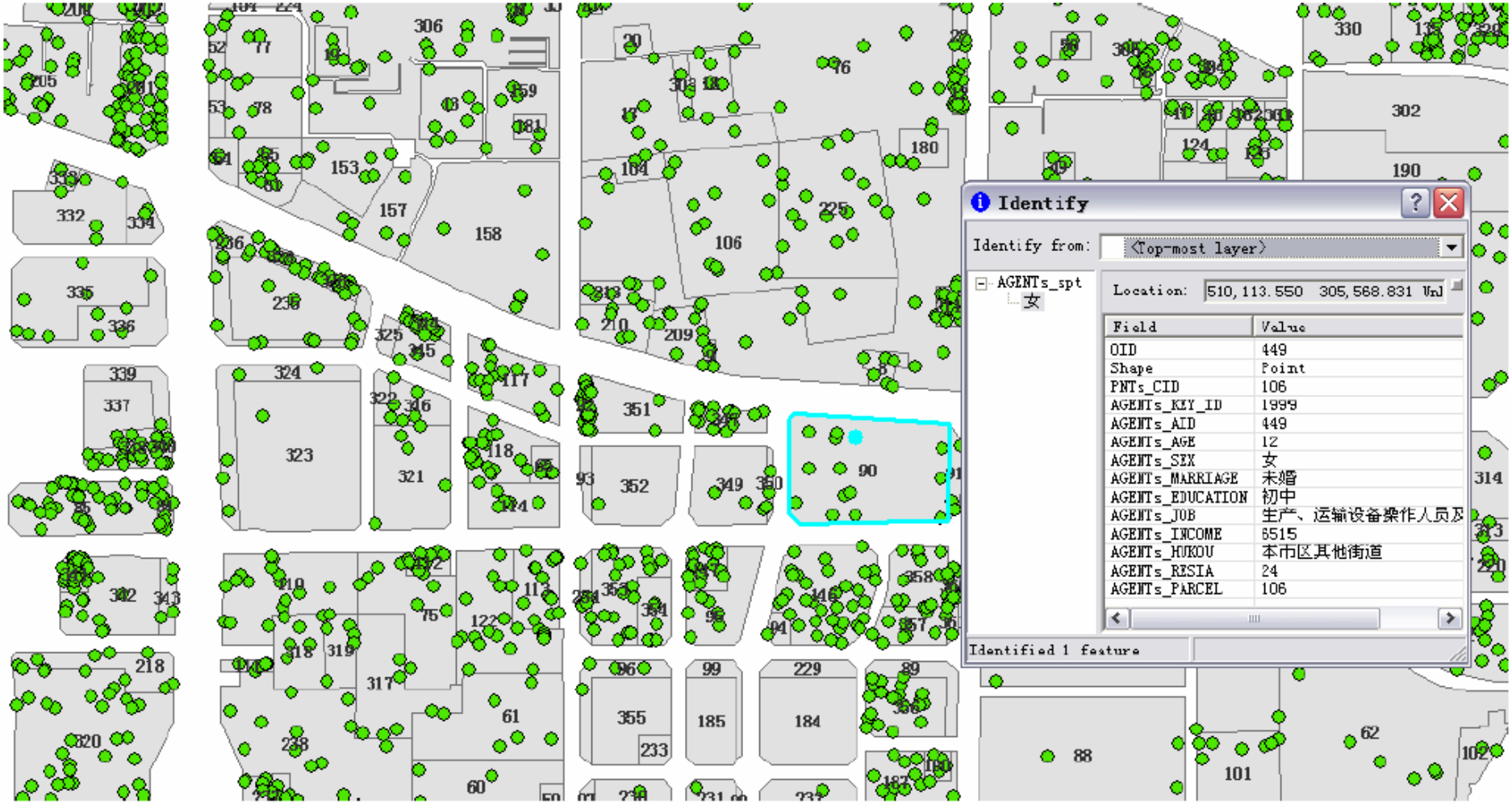
- **Samples**
- **Aggregated data**

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



- **Aggregated data**
- **Existing researches**

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.

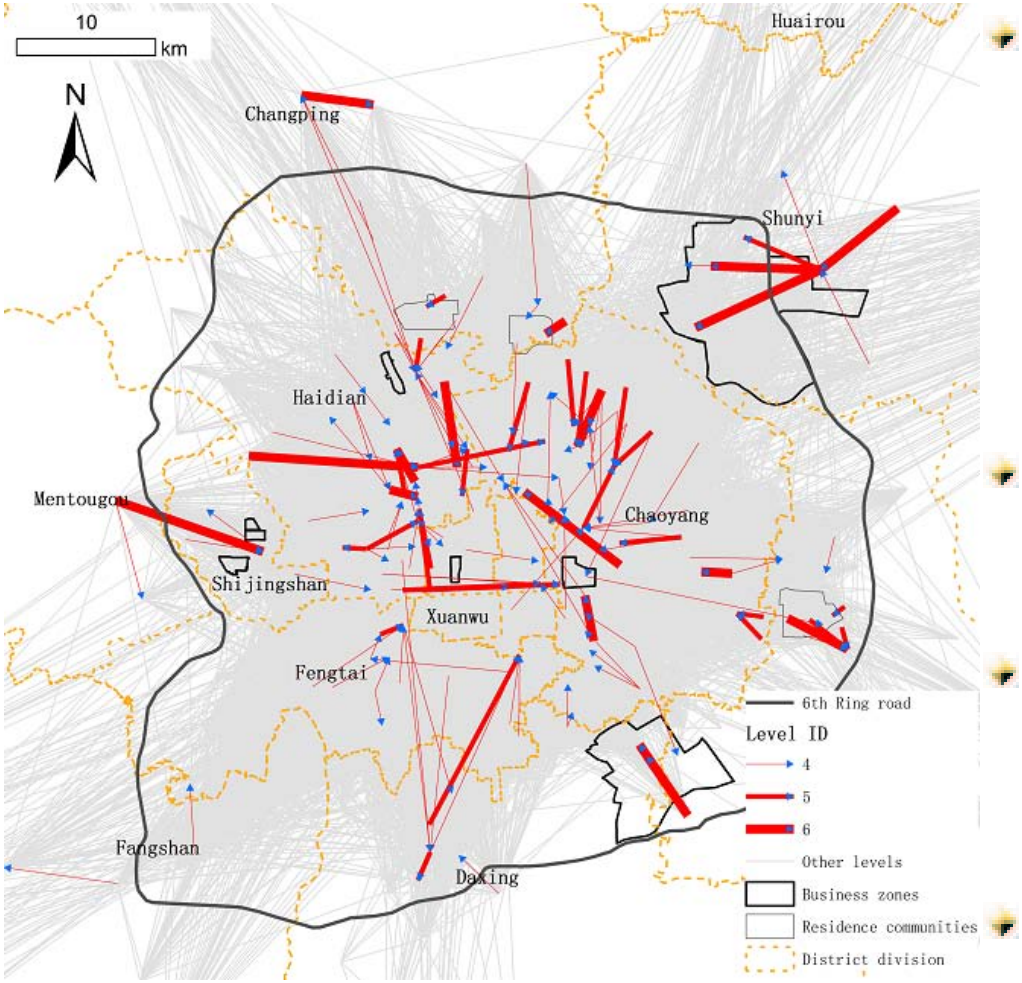
BEIJING100%: Human mobility

Travel purposes

- Work☐
- School☐
- Returning home☐
- Shopping☐
- Entertainment☐
- Daily life☐
- Business☐
- Other☐

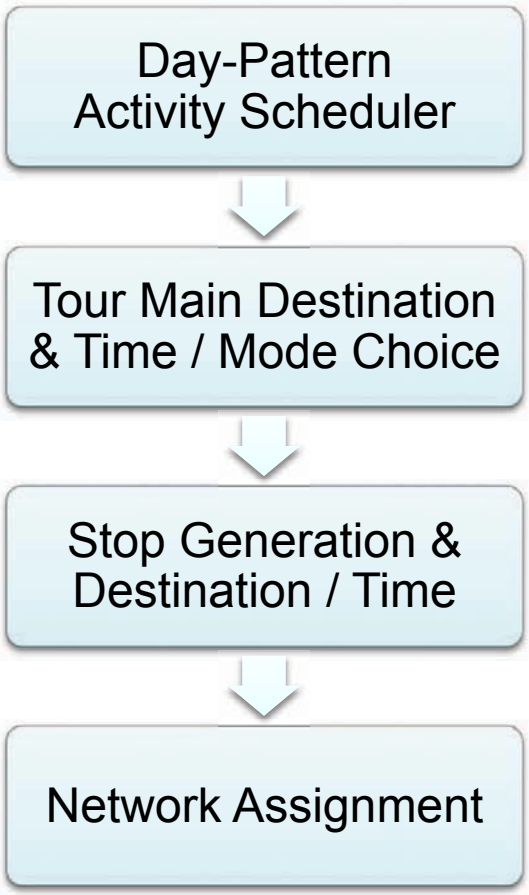
- The Beijing Household Travel Survey in 2010
  - 46,900 households / 116,142 persons surveyed
  - 253,584 trips (52,640 commuting from housing to job)
  - Information including
    - Socio-economic attributes of households and persons
    - One-day travel diary of each person (mode, purpose, OD, departure 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

-- Inferring urban activities from big data

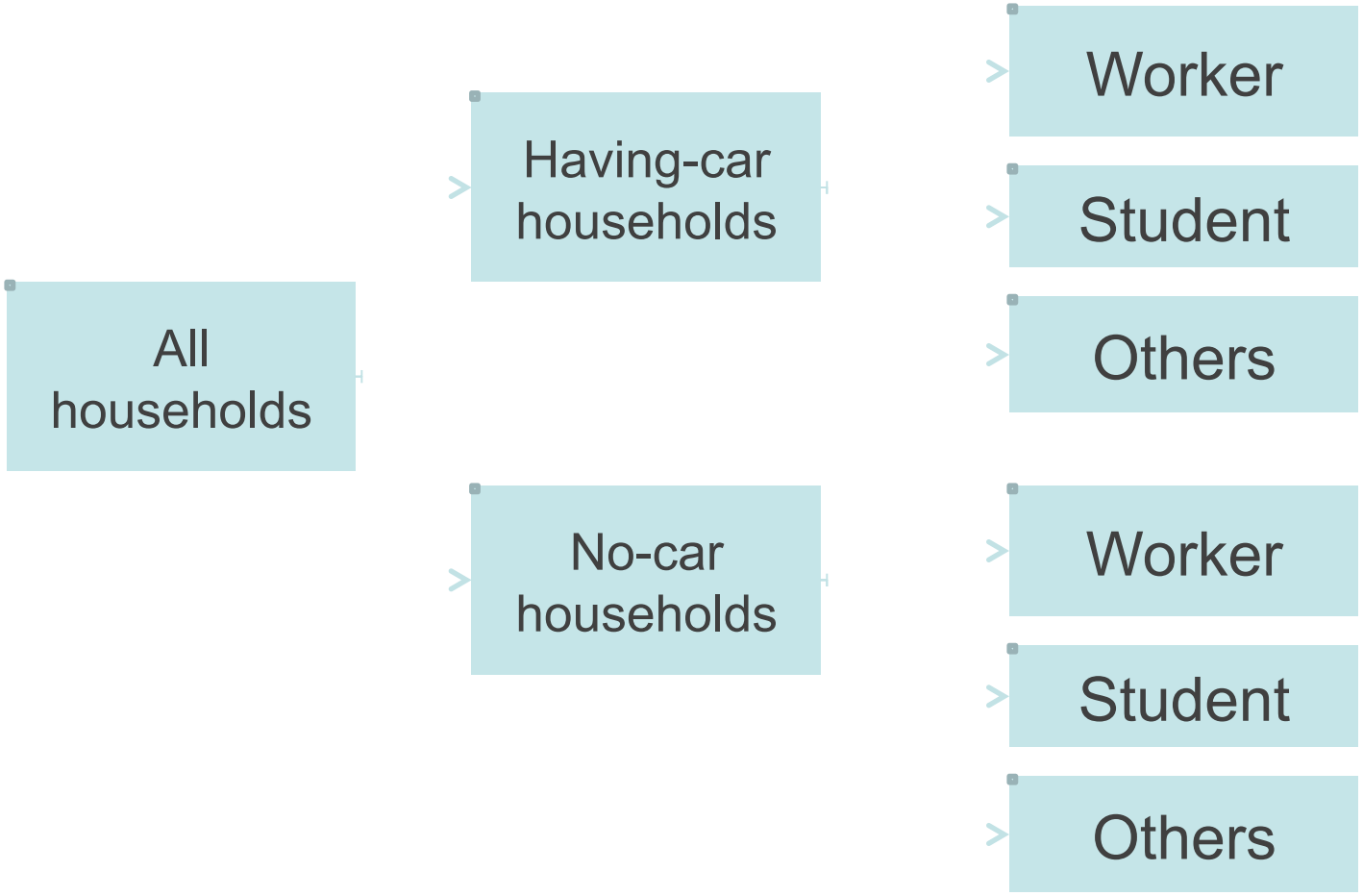


- Smart card data of Beijing in 2010
  - Bus and metro ridings
  - 10.9 million cards
  - Over 100 million swaps
  - Finishing identifying commuting trips
- Crawled from Weibo
  - China “Twitter”
  - Check In
- Taxi trajectories
  - Microsoft Research Asia (MSRA)
  - 30,000 taxis
- Combined with POIs
  - 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

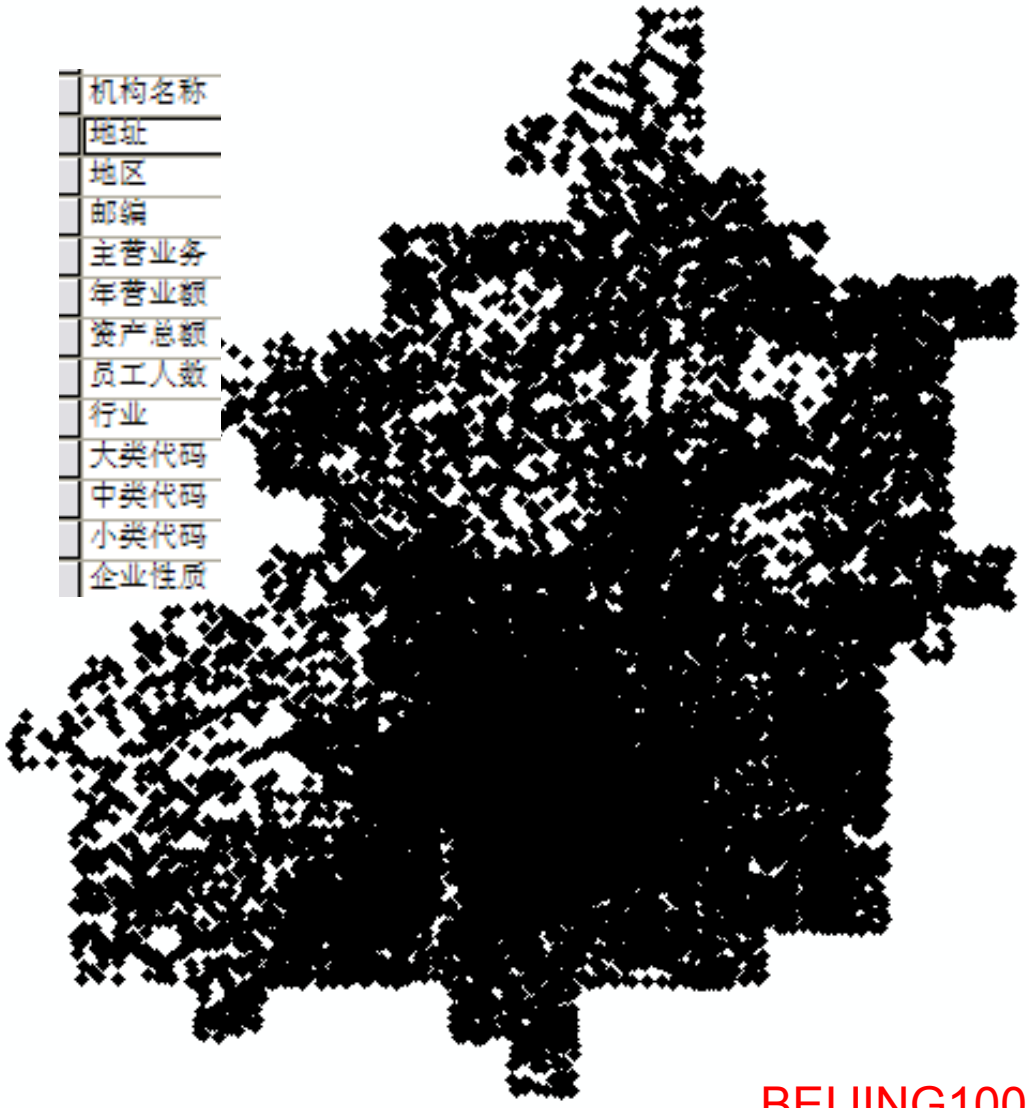
Trip chains of no-car workers

ID	Chain	Ratio（%）	Note
1	**HWH**	**62**	**家-单位-家**
2	**HWHWH**	**7.9**	**家-单位-家-单位-家**
3	HWEWH	2.9	家-单位-就餐-单位-家
4	HSH	2.7	家-购物-家
5	HWSH	1.8	家-单位-购物-家
6	HOH	1.7	家-其他-家
7	HWHSH	0.8	家-单位-家-购物-家
8	HWHLH	0.7	家-单位-家-娱乐-家
9	HLH	0.7	家-娱乐-家
10	HPWH	0.5	家-接送-单位-家
11	HPWPH	0.5	家-接送-单位-接送-家

N = 29774, Sum of ratios = 82%

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

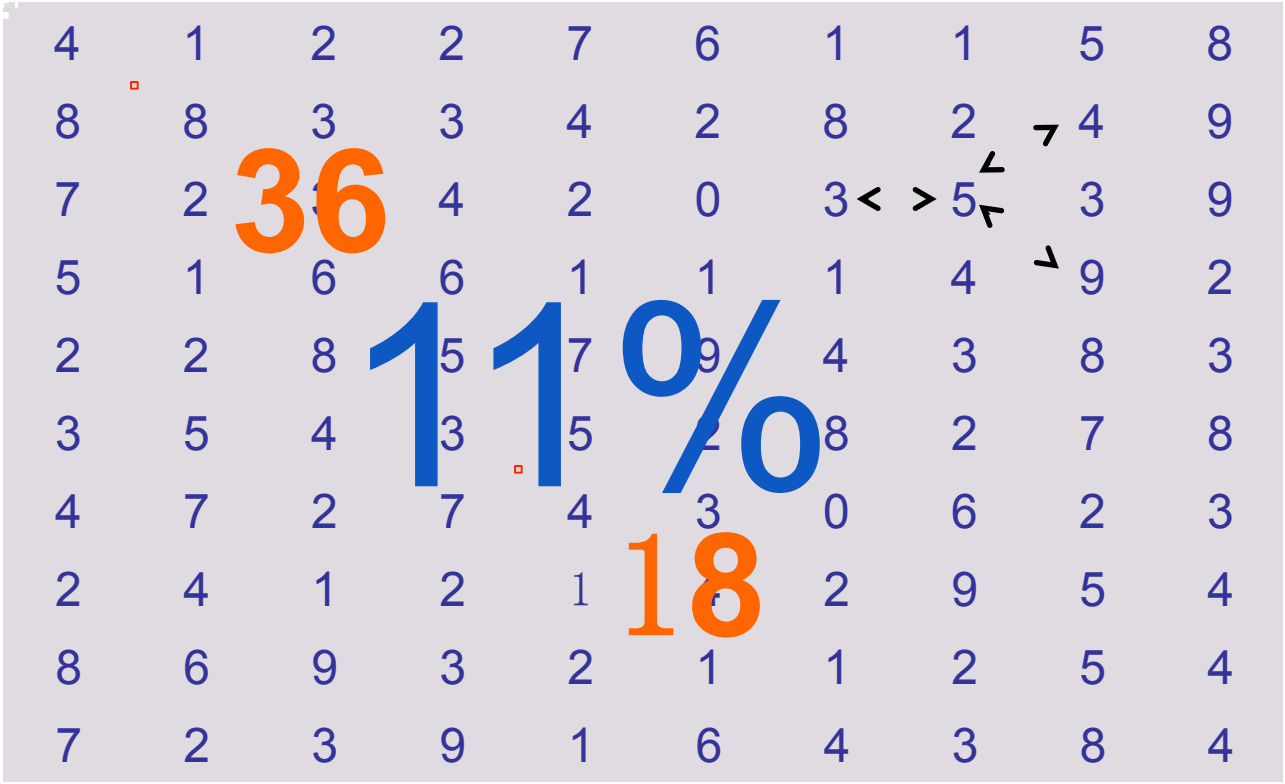
BEIJING100%: Firms



- 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)

→

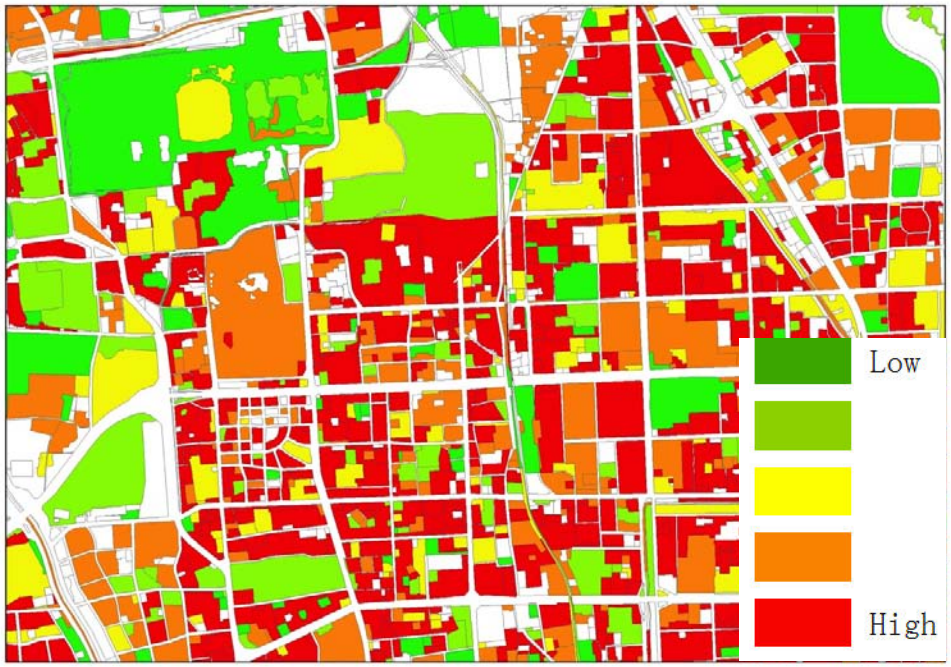
Feedback and decision by individuals

→

Macro behavior and spatial heterogeneities

What could the plan response?

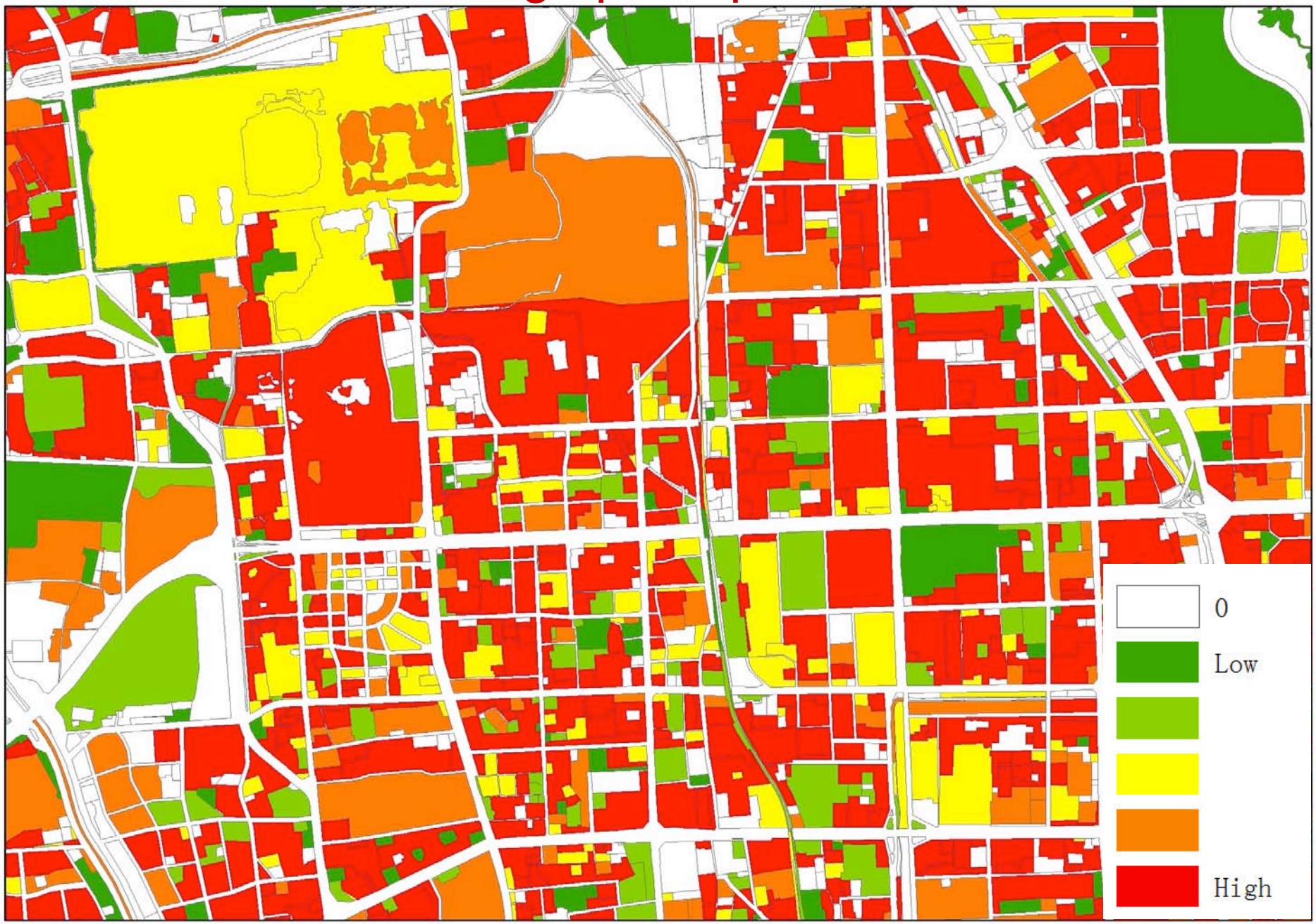
Case 1: Environmental evaluation□



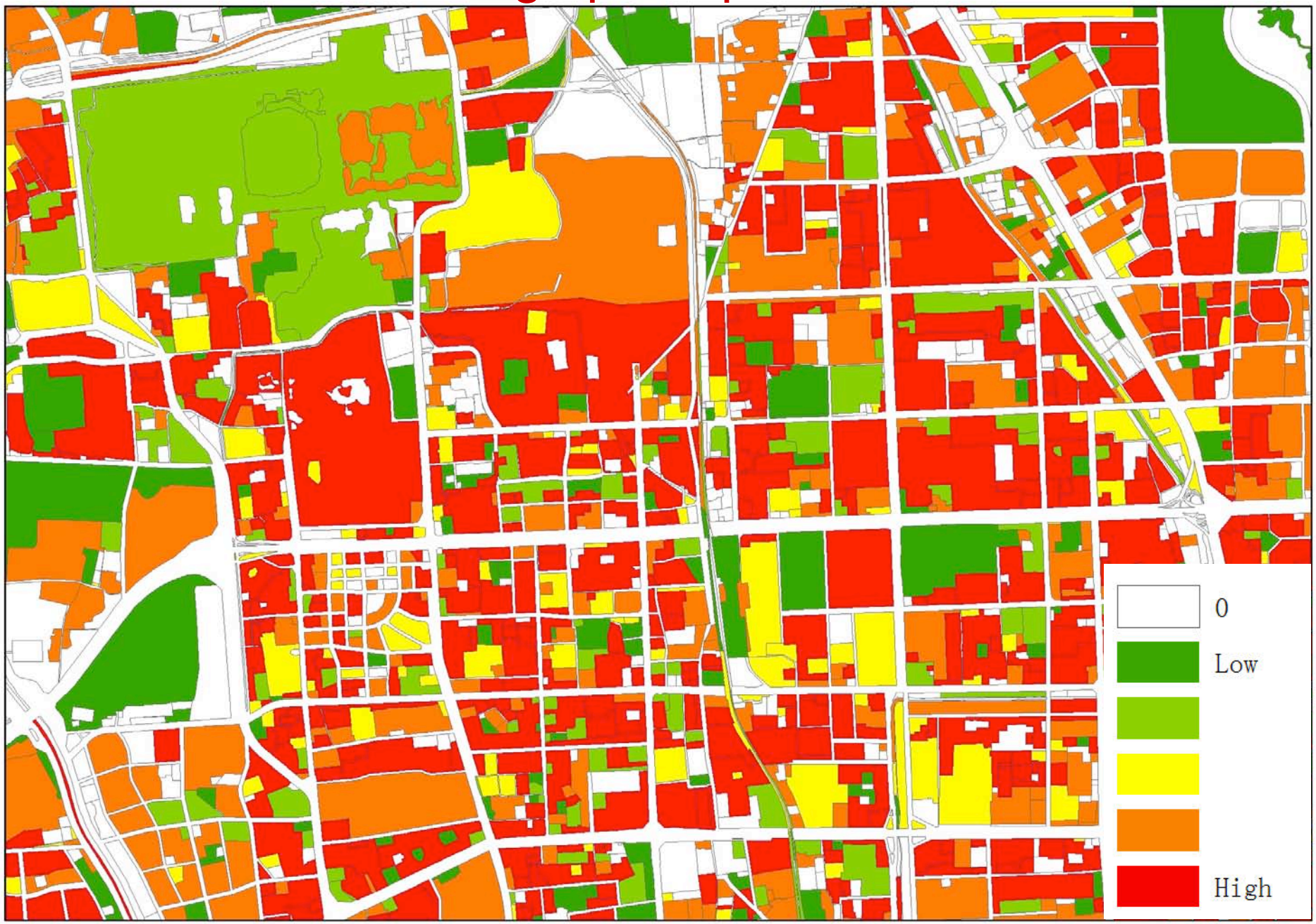
Energy consumption per sqkm

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

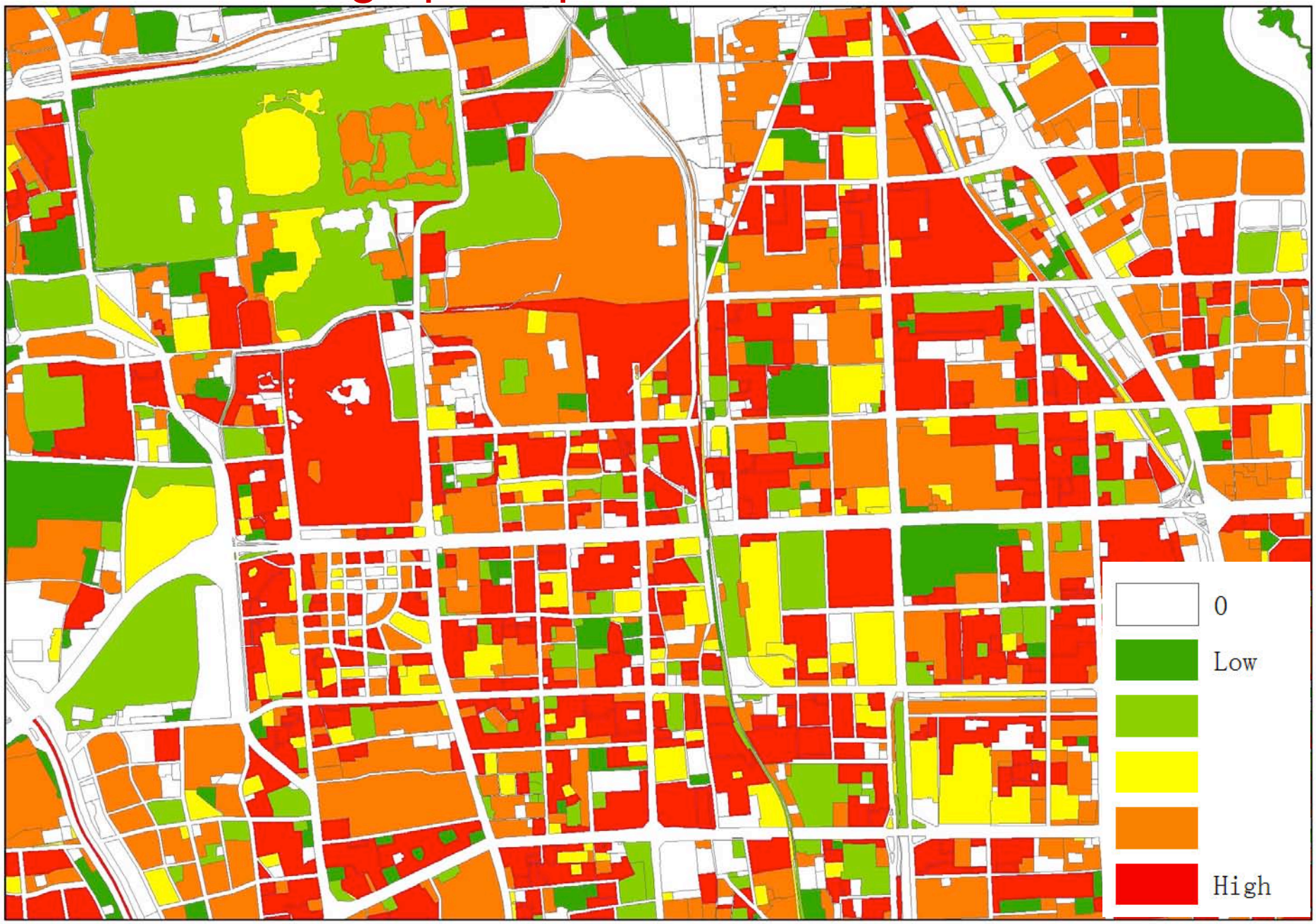
Wastewater discharge per sqkm



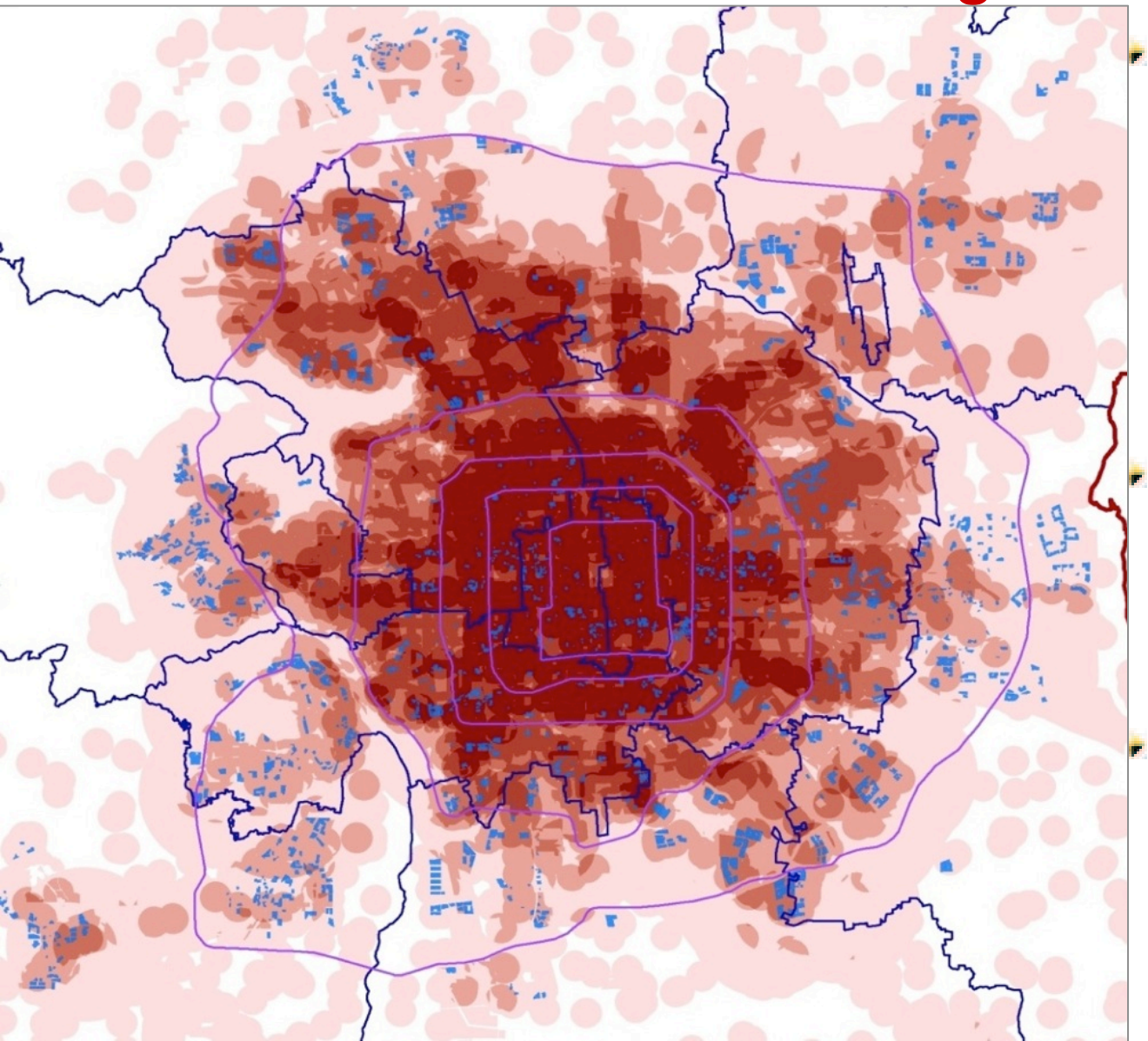
Solid waste discharge per sqkm



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 BEIJING100%
- 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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