Comparison of land use change models with focus on spatial and temporal frameworks and data issues

Martin Herold, Geog 220

Why ?

1. " Always remember that the selected model will be constrained by the data availability " (*EPA 2000, S. 20*)
2. Little consideration in reports
3. Complex models – require extensive data basis (Cause of concern or challenge):
   - Spatial accuracy
   - Temporal resolution
   - Various kinds of data with high thematic requirements
4. Focus of my research: Mapping of urban areas using remote sensing data

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Adaptation of the land cover classification scheme for County or a small city (*modified after Kaiser et al. 1995 cited in EPA 2000*)

<table>
<tr><td rowspan="10">URBAN</td><td rowspan="3">Residential</td><td>Low-density</td></tr>
<tr><td>Medium-density</td></tr>
<tr><td>High-density</td></tr>
<tr><td rowspan="3">Commercial</td><td>Mixed-use (commercial/residential)</td></tr>
<tr><td>General retail (central business district)</td></tr>
<tr><td>Professional services and office</td></tr>
<tr><td rowspan="3">Industrial</td><td>Light industry/warehousing</td></tr>
<tr><td>Heavy industry</td></tr>
<tr><td>Industrial/Research park</td></tr>
<tr><td>Other Urban</td><td>(Open space, Transportation)</td></tr>
<tr><td rowspan="5">Non URBAN</td><td rowspan="2">Agriculture</td><td>Cropland</td></tr>
<tr><td>Orchard</td></tr>
<tr><td rowspan="2">Forest</td><td>Deciduous</td></tr>
<tr><td>Evergreen</td></tr>
<tr><td>Protected Areas</td><td></td></tr>
</table>

How ?

Model Selection and Comparison:

- 7 Models from both reports (overall: 36 different)
- Regional scale models with following features:
    - Simulation focused on prediction of spatial land use pattern, especially urban land use
    - Model on generalized level (regional)
    - Documentation available and sufficient
    - more or less free available e.g. non-commercial or "contact developer"
        - Problems with commercial models:
            - Customized to accommodate user's own data
            - Generally very data intensive, high spatial/thematic accuracy
            - No detailed description of modeling approach (black box)
            - e.g. MEPLAN, Smart Places, INDEX, DRAM/EPAL
    - CUF 1,2, LUCAS, What If?, UPLAN, LTM, UrbanSim, Clarke Model
    - Other interesting models UGrow, Smart Growth Index
- Research sources:
    - USFS Report: Data and Data Integration (pp. 40-43), Information for models
    - EPA Report: Choosing the right model (pp. 18-22), Information for models
    - Documentations for the single models

California Urban Future 1 + 2 (CUF)

John Landis et al., UC Berkeley

Landis, J. D. 1994: The California Urban Futures Model: a new generation of metropolitan simulation models, Environment and Planning B, 21, pp. 399-420

Landis. J. & Zhang. M 1998: The second generation of the California urban futures model: Part 1: Model logic and theory, Environment and Planning B, 30, pp. 657-666

Model Objective

- Framework for simulation how growth and development policies might alter the location, pattern, and intensity of urban development

Modeling Approach

- Based on trend prognosis of economic and population development
- Calibration of statistical model parameters of observed/historical growth pattern in a fixed time frame to project future land use pattern for the same time frame

Spatial Framework

- CUF 1: Prediction for developable land units (DLU's) – aggregated vector information
- CUF 2: Raster-based / 100x100m grid cells (DLU)

Examples of required data

- Urban land use:
    - residential (single family, multiple family housing)
    - commercial
    - industrial
    - transportation
    - public
- Vacant land (aggregated information)
- Digital elevation model
- Socioeconomic information:
    - Population (tabular, city and county level)
    - Employment at (tabular, ZIP Code area)

Temporal Resolution

- fixed time steps based on historical calibration time frame

Land Use Change Analysis System (LUCAS),

M.W. Berry et al., University of Tennessee

Berry M. W., Flamm R. O., Hazen B. C. & MacIntyre R. L. 1996: The Land-Use Change and Analysis System (LUCAS) for Evaluating Landscape Management Decisions, IEEE Computational Science & Engineering, 3, 1, pp. 24-35

MacIntyre R. L., Hazen B. C. & Berry W. M. 1994: The Design of the Land-Use Change and Analysis System (LUCAS): Part I - Graphical User Interface, http://www.cs.utk.edu/~lucas/publications/gui/report.html

Model Objective

- examine the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability

Modeling Approach

- Premise of the model: landscape properties such as fragmentation, connectivity, spatial dynamics, and the degree of dominance of habitat types, are influenced by market processes, human institutions, landowner knowledge, and ecological processes.
- transition probability matrix - statistical, based on historical time series analysis of land cover change under consideration of population density, road networks and physical properties of landscape ▶ simulation of landscape change ▶ impact assessment on species, particularly based on landscape metrics

Spatial Framework

- Raster-based, particular patch based
- Grid cells 90 x 90 m

Examples of required data

- Land cover map (vegetation, Anderson Level I, particular II)
- Digital elevation model
- Socioeconomic data
    - Population density
    - Ownership (land holder characteristics)
- Transportation network (distance to roads, cities)

Temporal Resolution

- Variable (100 years prediction, 5 year time step)

What if?

R.E. Klosterman, University of Akron, Ohio

Klosterman, R. E. 1999: The What if? Collaborative planning support system, Environment and Planning B: Planning and Design, 26, pp. 393-408

Model Objective

- planning support systems to support traditional planning activities such as land use planning and urban modeling and emerging modes of collaborative planning
- creates alternative visions for the future in dependence of local land development policies

Modeling Approach

- bottom up model - UAZ (uniform analysis Zone)
- different modules:
    - land suitability analysis ▶ defining and weighting of factors for each land use type as well as allowed land use conversions
    - project future land use demand interactive definition of alternatives and scenarios
    - allocate most suitable locations by combining results of land suitable analysis and projection of future land use

Spatial Framework

- vector-based
- UAZ (uniform analysis Zone) – homogenous land units – model entities
- GIS overlay of all relevant layers of natural and human made features:
    - Zoning districts and planned land uses
    - Sewer and Water Service
    - Topography (Slope)
    - Proximity to intersections and major streets
    - Administrative borders

Examples of required data

- Urban land use:
    - Residential
    - Commercial
    - Industrial
- Digital Elevation Model
- Socioeconomic data (tabular data for every land use category):
    - Residential - intensive households parameters
    - Commercial/Industrial – e.g. employment vacancy rates
- Transportation infrastructure

Temporal Resolution

- Variable (example: 25 years prediction, 5-10 years time step, max. 5 periods)

UPLAN Urban Growth Model

D. Shabazian & R. Johnston, UC Davis

http://snepmaps.des.ucdavis.edu/uplan/

Model Objective

- Land use evaluation and change analysis tool to help communities to create alternative development pattern based on local land development policies

Modeling Approach

- Creates specific parameter grids
    - Attractive grids (locations for future developments)
    - Exclusion grid (no development possible)
    - General plan grid (regional general land use plan)
    - Existing urban grid (current land use conditions)
- Study area conditions - user defined decision criteria for grids
- Predicts future development by applying decision criteria

Spatial Framework

- Raster-based
- Resolution variable (50 x 50 m to 200 x 200 m)

Examples of required data

- Urban land use:
    - Residential (low, middle, high density)
    - Commercial (low, high density)
    - Industrial
- Digital elevation model
- Socioeconomic data:
    - Population projections (tabular)
    - Persons per household (class level)
    - Housing density per land use/average parcel size (class level)
    - Employment type and density
- Transportation Infrastructure

Temporal Resolution

- Variable (example: 20 to 40 years prediction)

Land Transformation Model (LTM)

B. C. Pijanowski, Michigan State University

Pijankowski, B.C, Long D. T., Gage. S. H. & Cooper. W. E. 1997: A Land transformation model: conceptual elements spatial object class hierarchy, GIS command syntax and an application for Michigan's Saginaw Bay watershed, http://www.ncgia.ucsb.edu/conf/landuse97/

Model Objective

- Simulation of land use change processes to forecast land use change based on ecological principles at the catchment scale

Modeling Approach

- Derivation of relative land transition probabilies from different driver variables:
    - Management authority (e.g. tax assessment, Land ownership)
    - Socioeconomic (population trends, employment)
    - Environmental (topography, drainage)
- Using complex GIS operations to predict future land use pattern

Spatial Framework

- Raster based
- Different spatial scales of processes:
    - 30 x 30 m – parcel
    - 100 x 100 m – plat
    - 300 x 300 m – block
    - 1000 m x 1000 m - local

Examples of required data

- Land cover map (Anderson Level I)
- Digital elevation model
- Socioeconomic data:
    - Locations of employment
    - Population distribution and change trends
    - Economics of land ownership
- Transportation Infrastructure

Temporal Resolution

- Variable (example: 20-50 year prediction, 5-10 years time steps)

UrbanSim

P. Waddell, University of Washington, Seattle

Waddell, P. 2000: A behavioral simulation model for metropolitan policy analysis and plannings: residential location and housing market components of UrbanSim, Environment and Planning B, pp. 247-263

Alberti M. &Waddell P. 2000: An Integrated Urban Development and Ecological Simulation Model, Integrated Assessment, in press, http://www.odot.state.or.us/tddtpau/papers/P2T2.4.2fnl.pdf

Waddell, P. 1998: UrbSim - The Oregon Prototype Metropolitan Land Use Model, in Proceedings of the ASCE Conference Transportation, Land Use, and Air Quality: Making the Connection Portland, Oregon, May 1998. http://www.urbansim.org/Papers/ASCE%20Model.pdf

Model objective

- Software-based system for integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy

Model approach

- Regional forecast ▶ demographic and economic transition
- Simulate choices of key decision makers (households, businesses, developers, government) that impact urban environment (object oriented model, microsimulation of actor choices: location, housing travel, production)
- Process-based model of physical and ecological dynamics based on GEM
- Spatial simulation which inherit the changes in land use/cover including structural issues (landscape metrics)

Spatial Framework

- vector-based at parcel-level for land development
- 150 x 150 m grid cells for environmental models

Examples of required data

- Household/Parcel level:
  - Parcel and household data including an intensive amount of socioeconomic parameters
  - Business establishments including various information
- Ecological level:
  - Land cover map (?)
  - Digital elevation model

Temporal Resolution

- Variable (example: 1 years time steps)

Clarke Cellular Automata Urban Growth Model

K.C. Clarke, UC Santa Barbara

Clarke, K.C., Hoppen, S ,& Gaydos, L., (1996) "Methods and techniques for rigorous calibration of a cellular automaton model of urban growth," Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, January 21-25, 1996. Santa Barbara: National Center for Geographic Information and Analysis

http://www.ncgia.ucsb.edu/projects/gig/clarke_ca.htm

Model objective

- Simulation of urban growth in order to aid in understanding how expanding urban areas consume their surrounding land and local environment

Model approach

- Simulate transition of non-urban to urban land use using raster cells (cellular automaton) based on mechanistic growth rules as well as a set of weighted probabilities that encourage or inhibit growth
- Land use change is predicted by growth rules based on:
    - Local factors (roads, existing urban areas, topography)
    - Temporal factors (e.g. historical pattern)
    - Random factors

Spatial Framework

- Raster based
- Base data 30 x 30 m resolution, model run at 50 m to 1 sq.-km level

Examples of required data

- Land cover map (Anderson Level I)
- Digital elevation model
- Transportation Infrastructure

Temporal Characteristics

- Variable (example: 90 years prediction, 1 year time steps)