GIS Applications for Demographic Estimation and Projection

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Arc-GIS as a Tool for Demography

- Arc-GIS serves as a software tool for:
  - Managing complex geospatial data.
  - Allocating demographic “events” in space to allow estimation and projection of populations.
  - Analysis of demographic data within an explicitly “spatial” framework.
Demography is Spatial

- Population dynamics are composed of “events” that happen across both space and time.
All Demographic Estimation and Projection Occurs in This Spatio-Temporal Context

- Population estimates track “events” over time and space that signal population growth.
- Here, we display population growth rates by census tract in Bernalillo County between 1990 and 2000.
Spatial Demography as a Process

- Events
  - Events Allocated in Space
    - Estimates Produced Within Desired Geographic Boundaries
      - Sub-Boundary Allocation of Estimates
        - Larger Area Estimates
          - Statistical Description of Spatial Patterning of Demographic Events and/or Estimates (Current or Historical)
            - Statistical Models of Spatial Patterning of Estimates
              - Spatial Forecasting of Population and Population Dynamics
1. Present a Brief Overview of the Population Estimation Process in a Spatial Context (Jack Baker)

2. Review Methods of Managing Geospatial Data for Population Estimation Using Arc-GIS (McDaniel)

3. Review Methods of Spatial Analysis with Applications to Demographic Estimations (Ruan)

4. Provide a brief example of a population estimate in a spatial context (Baker and Ruan)

5. Review potential future directions for GIS applications in Spatial Forecasting (Baker, Ruan, and McDaniel)
Estimating Population Within Geographic Boundaries

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Population Estimate “Inputs”

Population Estimates Can be Produced “Indirectly” or “Directly”:

1. Indirect methods track the construction and occupation of housing units, then estimate population based on this pattern.

2. Direct methods involve tracking “components” of change through an accounting procedure—births, deaths, and migration of individuals in and out of a given geography are counted.
Population = (Occupied Housing Units*Average Persons in Household) + Group Quarters Population
Housing Unit Based Estimation in a Geographic Context

1. Building Permit Data Collected → Building Permits Allocated to Geographies
2. Building Permits Allocated to Geographies → Occupancy and Persons Per Household Estimated
3. Occupancy and Persons Per Household Estimated → Population in Houses Estimated
5. Group Quarters Population Estimated → Total Population Estimated Via Housing Unit Method

Total Population Estimated Via Housing Unit Method
Component Population Estimation

\[
\text{Pop}_t = \text{Pop}_{t-1} + [(B_{t-1,t} - D_{t-1,t}) + (IM_{t-1,t} - OM_{t-1,t})]
\]

Or

Population = Population at Previous Year + [(Births – Deaths) + (In-Migration – Out-Migration)]
Component Estimation in a Geographic Context

Births

Deaths

Migration Events

Events Allocated to Geographies

Population Balancing Equation Applied to Previous Population

Population Estimates
Composite Methodologies

- Both housing unit-based methods and component methods are both employed by BBER in producing population estimates.
- The two methods should converge upon similar results, increasing validity of estimates.
Arc-GIS as A Data Management and Spatial Allocation Tool

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Allocating Demographic Events in Space: Geo-coding

- Producing population estimates within geographic boundaries requires correct allocation of events into appropriate spatial units.
- This is accomplished through a process known as “geo-coding”.
Geo-coding Defined

- The process of converting descriptive locations (i.e. addresses) into geo-referenced locations (x,y location).

- This is achieved by referencing an address to a location on a road network.

- Also know as Address Matching
Geo-coding: Getting Spatial

- Putting “administrative” data into a spatial context.
- Assigning each address a geographic location (i.e. XY coordinate).
- To determine where the address is in space (Census Geography, etc.)
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<td>Standard Address Format</td>
<td>Township Range Section</td>
<td>Total</td>
<td>Trailer Park - Mobile Home</td>
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<td>8885</td>
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</table>

^ Summary Output

Spatial Data >
Geo-coding Workflow

- Preprocessing: Key entering, cleaning (majority of time).
- Processing: geo-coding
- Post-processing: documentation
Why Geocode?

- Many reasons: One important reason is to be able to determine which boundary (e.g. school district, census block, voting district) a particular address is contained within.

- To extract information from an address that the address does not immediately offer.
The Data – What is Needed?

- Address File

- Topologically correct road network
  - Address range fields
  - Name Field

Mapquest.com
Data Sources

Input Data (Attribute Data)
• Vital Records
• NMCID
• MRCOG
• City Governments (For SPIP)

Spatial Data
• ESRI – www.esri.com/data
• TeleAtlas – www.teleatlas.com
• US Census Bureau (TIGER) – www.census.gov
Data Problems

- Inconsistent
- Incomplete
- Not in the correct address format.
- Data not collected for research purposes
- Reconciling Census Geography
'Cleaning’ the Data

- Putting data into the correct format
  - Taking out PO Boxes, Apartments #s etc.
- Indexing – Adding a Unique Identifier
  - To tie data together and trace back
- Documenting – Coding, Summarizing
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<tr>
<th>CODE</th>
<th>DESCRIPTION</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Trailer Park / Mobile Home Park</td>
</tr>
<tr>
<td>2</td>
<td>No street number, only a street name.</td>
</tr>
<tr>
<td>3</td>
<td>An Apartment with no street address given</td>
</tr>
<tr>
<td>4</td>
<td>Directions given, but no street info (Ex: 1/2 Mile E on Hwy 70)</td>
</tr>
<tr>
<td>5</td>
<td>Mile Marker</td>
</tr>
<tr>
<td>6</td>
<td>PO BOX</td>
</tr>
<tr>
<td>7</td>
<td>Missing - No street data at all!</td>
</tr>
<tr>
<td>8</td>
<td>General Delivery / Rural Route</td>
</tr>
<tr>
<td>9</td>
<td>Township Range</td>
</tr>
<tr>
<td>10</td>
<td>Lot # or Tract (legal description)</td>
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## Incorrect Address Formats

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<td>2</td>
<td>CAMINO DE LOS CHAVEZ</td>
</tr>
<tr>
<td>3</td>
<td>CASTLE APRT</td>
</tr>
<tr>
<td>4</td>
<td>2 MILES WEST OF CAPITAN</td>
</tr>
<tr>
<td>5</td>
<td>MM 278 HWY 70</td>
</tr>
<tr>
<td>6</td>
<td>PO Box 862</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
<td>GENERAL DELIVERY</td>
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<tr>
<td>9</td>
<td>T16SR13E30</td>
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<tr>
<td>10</td>
<td>TRACT 2 MAP 70</td>
</tr>
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</table>
Accuracy of Matches

- Are the points being placed where they should be?
- Depends upon accuracy of address and road network.
- Score
- Informal Checks
  - Compare against existing data, known points.
  - Check against Zip Code boundaries, quadrants
Reconciling Census Geographies

- Tracking long-term trends in population events, components, or totals is made difficult by changing definitions of geographic boundaries such as:
  - City incorporation.
  - County incorporation (e.g. Cibola split from Valencia county in the 1970s)
  - Census boundary changes (tracts, block groups, and blocks)
Bernalillo County Census Geography in 1990

110 Tracts
Bernalillo County Census Geography in 2000

141 Tracts
Fundamental Problems in Reconciling Census Geographies

1. 1990 and 2000 Census tract boundaries obviously do not correspond to one another.
   - Trends between 1990 and 2000 cannot be assessed without accounting for these differences because boundary shape files differ.

Attempts to unify the data contained in “shape” files from each Census leads to a second fundamental question:

2. How do we re-distribute variable values from 1990 tracts to 2000 tracts when a 1990 tract may now be placed in multiple 2000 census tract boundaries?
Geographic Boundary Intersection and Allocation

What proportion of the 1990 population lays within this area of overlap and should be allocated to the new 2000 boundary?
Allocating 1990 Values to 2000 Geographies

If we assume that population or demographic events are evenly and randomly distributed across the 1990 and 2000 tracts, then we may allocate them based on the proportional area occupied by the area of overlap.
To estimate the 1990 population in the area of overlap that should be allocated to the new 2000 geography, we use a proportional allocation equation based on the relative area of the area of intersection to that of the entire 1990 tract:

\[ \text{Pop}_{2000} = \text{Pop}_{1990} \times \left( \frac{\text{Intersection shape area}}{\text{1990 Area} \times \text{Pop}_{1990}} \right) \]
In Review

The two key issues in GIS data management for spatial applications in demography are:

- assigning data to locations in space (geo-referencing).
- adjusting data for changes in geographic boundary definitions.
Spatial Analysis for Demography

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Introduction
Why Spatial Analysis?

Tobler’s “First Law of Geography”

“Everything is related to everything else, but near places are more related than far places.”
Uses of Spatial Analysis

1. To appropriately measure spatial effects (effects of proximity).

2. To identify spatial effects and their causes.

3. To incorporate spatial effects into other models--including forecasting models.
Spatial Analysis Defined

Spatial Analysis, then, is a quantitative data analysis technique in which the focus is on the role of proximity in space in understanding patterns of variation.
Methods of Spatial Analysis

- **Spatial Auto-correlation Analysis**
  - Describing the correlation of a variable with itself through space--appropriately describes spatial relationships.

- **Spatial Regression Analysis**
  - Regression methods adjusted for spatial autocorrelation--allows estimation of effects and modeling with adjustment for confounding effects.

- **Spatial and Space/Time Forecasting (STARMA models)**
Spatial Autocorrelation

Describing Spatial Effects
Neighborhood Relationships

- Define nature of relationships between variables within geographic boundaries that are spatially close or near.
- Must be defined prior to estimation of spatial auto-correlations.
Defining “Neighborhood” Relationships

Definition of neighborhood → Neighbor Weight Matrix

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<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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Neighbor Weight Matrices

1. Contiguity Neighbors
   - Rook contiguity (neighbors share a border)
   - Queen contiguity (neighbors share a “point”)

2. “Within Certain Distance” Neighbors
   - Geographic “centroids” must be pre-defined
   - Number of “neighbors” may be specified

3. Other Types of Neighbors
   - Same longitude or latitude are neighbors
   - Example: neighbors along a transportation system.
Spatial Auto-correlation Statistics

- Spatial auto-correlation can now be carried out with definition of nature of neighbor weight matrix.
- Two principal statistics are used to measure the correlation of a variable with itself through space:
  1. Moran’s I
  2. Geary’s C
Global Moran’s “I” Statistic

\[ I = \frac{z' W z}{z' z} \]

- \( z \) is a vector of variable values expressed as deviations from the mean,
- \( W \) is the weight matrix.

- How to test: Ranges from -1 to 1, Z-value based on I follows standard normal distribution

- Target
  - Indicates presence and degree of spatial auto-correlation among variable values across spatial units
Local Moran’s “I” Statistic

\[ I_i = Z_i \sum_j W_{ij} Z_j \]

- \(Z_i\) is the standardized variable value at a particular location,
- \(Z_j\) is the standardized variable value at defined neighbor location,
- \(W_{ij}\) is a weight applied to the comparison between location \(i\) and location \(j\).

- How to test: same as global I

- Target
  - Decomposes global measure into each unit’s contribution
  - Identifies local “hotspots”, areas which contribute disproportionately to global Moran’s I
Representing Auto-correlation Graphically

NM Population Growth Rate Auto-correlation 1990 - 2000

- Once neighbor weight matrices are defined and spatial auto-correlations are estimated, these relationships may be represented graphically.
Once spatial auto-correlations are identified, spatially-modified regression techniques may be used to assess their causes.

Two primary techniques:

1. Spatial Error Model

\[ y = X\beta + \varepsilon \]

Where: \( \varepsilon = \lambda W \varepsilon + (\text{insert symbol here}) \)

2. Spatial “Lag” Model

\[ y = pW y^* + X\beta + \varepsilon \]
Spatial Forecasting Models

- Once properly specified, spatial regression models may be extended to forecast values across space, and, potentially, time as well.
Sample Estimation Using Bernalillo County Census Block Groups

Using Geo-referenced Data for Population Estimates and Spatial Analysis
Housing Unit Based Estimation Equation

\[ \text{Pop}_t = (\text{HU}_t \times \text{OR} \times \text{PPH}) + \text{GQ}_t \]

Population = (Occupied Housing Units*Average Persons in Household) + Group Quarters Population
Housing Unit Based Estimation in a Geographic Context

1. Building Permit Data Collected
2. Building Permits Allocated to Geographies
3. Occupancy and Persons Per Household Estimated
4. Population in Houses Estimated
5. Group Quarters Population Estimated
6. Total Population Estimated Via Housing Unit Method
Spatial Population Estimates

Housing Unit Based Estimates With Spatial Autocorrelations
### San Juan County

- **City of Alamogordo**
## Example Building Permit Data for Geocoding

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<tr>
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<th>Number</th>
<th>Street</th>
<th>Type</th>
<th>City</th>
<th>Zip Code</th>
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<td>87000</td>
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</table>
ArcData

Download Census 2000 TIGER/Line® Shapefiles

You have selected the state of New Mexico. If you would like to download one or more data layers for a single county in New Mexico, then select a county from the list below. If you would like to download a single data layer for one or more counties in New Mexico, then select a layer below.

Select by County  OR  Select by Layer

Select a County  Select a Layer

Submit Selection  Submit Selection

Technical documentation for PL 94-171 and SF1 data:

U.S. Census PL 94-171(PDF)

U.S. Census Summary File 1 (SF1)(PDF)

ESRI Abbreviated PL 94-171(PDF)

PL 94-171 Quick Reference Guide

SF1 Quick Reference Guide
**ArcData**

**Download Census 2000 TIGER/Line® Shapefiles**

You have selected **Bernalillo County** for the state of **New Mexico**. Below is a list of the data layers that are available for this county. Not all data layers are available for each county. You can check the data layers that you would like to include in your download. Each data layer is listed with its compressed file size (.ZIP). You may select up to 20.0 MB of compressed data in a single download.

<table>
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<th>Available data layers</th>
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[NOTE: The URL mentioned at the bottom of the image is for demonstration purposes and may not be the actual link.]
April 01, 2000 to December 31, 2000 Bernalillo County Building Permits by Block Group
Example Estimate: Bernalillo County, Tract 37.30, Block Group 3
Bernalillo County Census Tract 37.30, Block Group 3
Example Population Estimate: Housing-Unit Based Method.
Tract 37.30, Block Group 3, Bernalillo County 2001

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Spatial Autocorrelation: Bernalillo county 1990 to 2001 Census Block Group Population Density
Conclusions

- Use of Arc-GIS technology allows the production of sub-county and other “small area” population estimates and projections.
- Use of related spatial analytic tools provides greater understanding of the spatial patterning of demographic trends over time.
Future Directions in Spatial Population Estimates and Projections

Directions in Research and Development at BBER
The example presented here suggests that incorporation of spatial thinking into demographic estimation and projection may enhance our predictive power and understanding of demographic processes.
Spatial Forecasting

- Historically, BBER has produced population estimates and projections that while situated geographically, did not explicitly consider spatial relationships (the effects of proximity).

- A clear extension of this process is to use ARC-GIS tools to extend our estimation and projections not only into future times, but also into space—“on the ground”.
Research and Development

- Using ARC-GIS, BBER is currently conducting research and development on this process.

- Goals include production of sub-county estimates within census boundaries (tracts) as well as production of spatially explicit population forecasts at all geographic levels.