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# A Planning Support System for Comprehensive Planning and Zoning: I. Mapping the Morphology of Urban Sprawl and Blight II. A Geospatial Simulation Model of Land Use, Land Cover Change for the Memphis Metropolitan Region


Reza Banai, Ph.D., Co-Principal Investigator, Department of City and Regional Planning
Youngsang Kwon, Ph.D., Co-Principal Investigator, Department of Earth Sciences

University of Memphis


**Smart Cities Research Initiative**

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# Introduction

To aid the City of Memphis comprehensive planning process, we first diagnose historical pattern of sprawl that a long-term comprehensive plan aims to counter. We do this in two parts. We map the sprawl-and, its phenomenally-related, blight- morphology of the Memphis metropolitan region in part I. In part II a geospatial model maps land use trend or “business as usual” projected to 2040. This model provides a decision support system for planning smarter growth alternatives, with efficient public transportation, walkable communities, viable centers, open space, natural resource conservation.

# Methods: I. Mapping the Morphology of Sprawl with Shannon entropy

Shannon’s entropy index is used to quantify the degree of dispersion (i.e., land use or land cover mix), or concentration of built-up areas by type of land cover and land use. Increasing entropy values - continuous dispersion with built-up areas - indicate trends of urban sprawl while decreasing values would reflect that an area is becoming less fragmented, thus, further occurrence of built-up is less likely. According to information theory, high entropy is the most probable yet least predictable state that leads to disorder. The same is true for urban sprawl. Shannon’s entropy is calculated thus (Yeh and Li, 2001):

$$\mathrm{H}_n = \sum_{i}^{n} p_i \log(\frac{i}{p_i})$$

where $p_i$ is the probability or proportion of occurrence of a phenomenon in the *i* th spatial unit out of n units, and thus, is given by:

$$p_i = x_i / \sum_{i}^{n} x_i$$

where $x_i$ is the area of built-up at the *i* th unit.

Entropy values range between 0 and 1, 0 being concentrated pattern, “coarse grain” while 1 being dispersed distribution, i.e. when there is a mixture of land use types or land cover categories (see Figure 1 which indicates eight categories of land cover). Thus the entropy (H) value can be treated as a critical limit or threshold to the expansion of area. Entropy values monitored over years provide quantifiable description of the urban situation to policy makers.

# Shannon Entropy Index of Land Cover, Land Use, and Transitions

Entropy values range between 0 and 1, indicating concentrated and dispersed pattern, respectively. Applied to land cover and land use, the range of entropy values from 0 to 1 effectively connotes less to more "mix" of land cover and or land use, or, alternatively, from "coarse grain" to "fine grain," respectively. Thus the entropy (H) value is regarded as a critical limit or threshold to the expansion of metropolitan region. Entropy values monitored over years provide quantifiable description of the extent of the sprawl of urban form to policy makers.

$$H'_n = \frac{H_n}{log_e(n)}$$

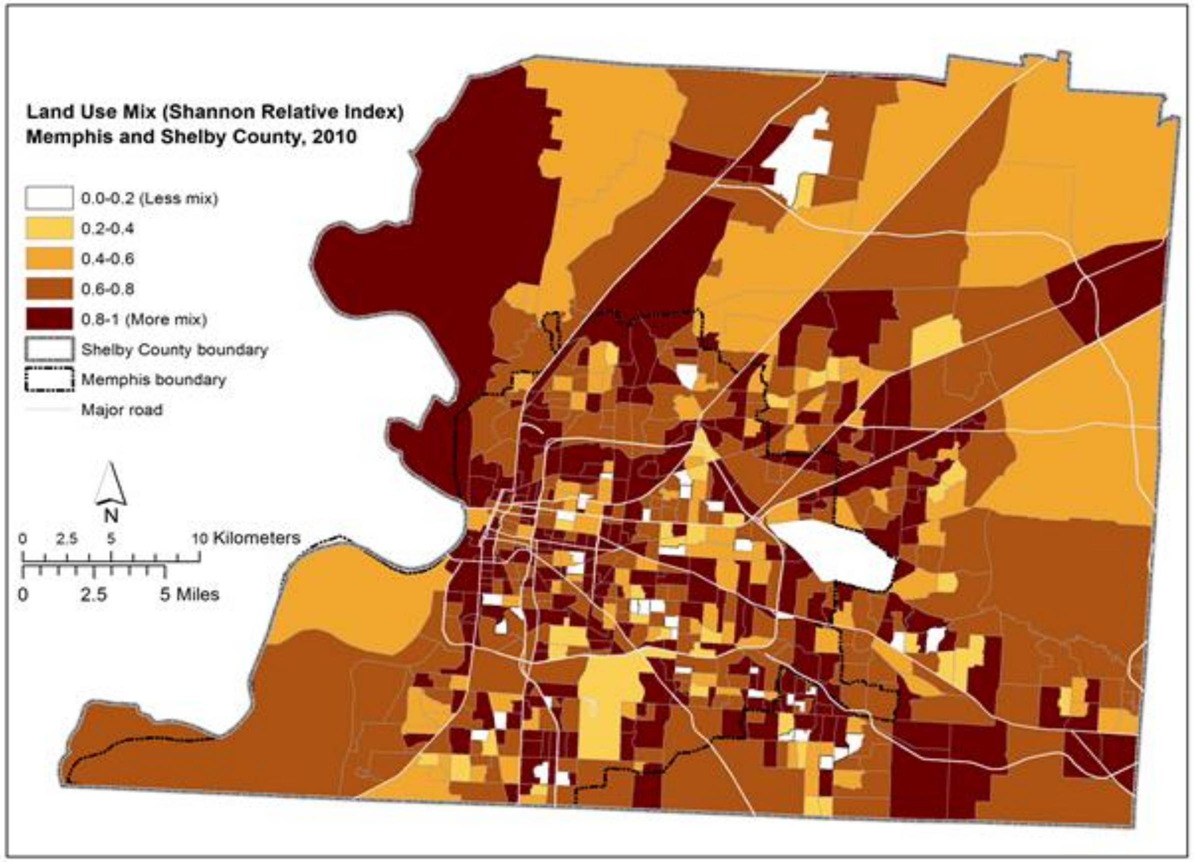
$0 \leq H'_n \leq 1$

change in entropy over time ($t$) is given as follows:

$$\Delta H'_n = H'_n(t+s) - H'_n(t)$$

We compute the change in entropy values over a decade (s) to determine whether the land cover and land use transition to more or less urban sprawl (dispersion).

# Shannon Entropy Index of Built-up Areas of Memphis and Shelby County by Block Group, 2010.




Shannon index of sprawl for the built-up is shown. Locations where a single land cover dominates, or low land use mix such as a regional public park (Shelby Farms park), shown to the east of interstate highway (I-240 loop) in the thematic map, is measured by entropy index value < 0.2.

## Block-Level Land Cover and Land Use Transitions

We mapped the morphology of sprawl in the Memphis metropolitan region at three geographical scales—census block group, city and county. Remotely sensed land cover (satellite) and parcel-level land use from county assessor GIS provided spatial data. We mapped both land cover and land use transitions over a decade to determine the spatial pattern of sprawl with Shannon entropy (Fig.)

Shannon index of sprawl for the built-up is shown in Figure. Locations where a single land cover dominates, or low land use mix such as a regional public park (Shelby Farms park), shown to the east of interstate highway (I-240 loop) in the thematic map, is measured by entropy index value < 0.2.

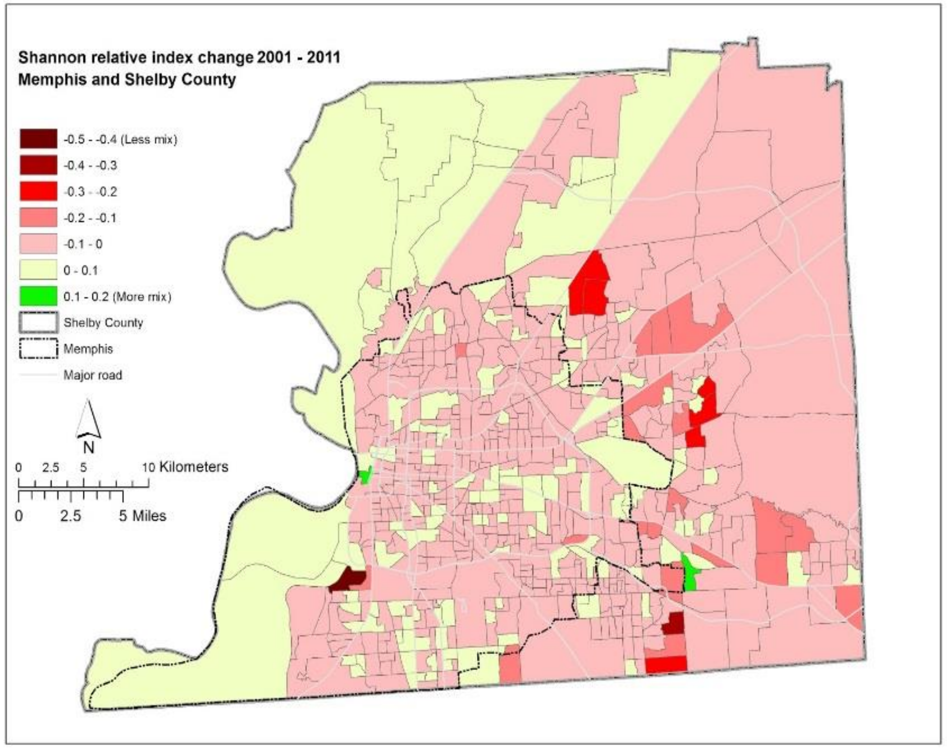
The suburban and exurban expansion of the City of Memphis into the greenfields of Shelby County and beyond is commonly known, but rarely measured. Our mapping shows the extent of land cover conversions for the period from 2001-2011. It turns out, “planted/cultivated” is the largest proportion of land converted to “developed” or built-up land. Add forest, shrub land, herbaceous, and even wetland and water (0.64), then the proportion of “nature” to development conversion is 1.74%. The significance of this value is realized as a proportion of total land area of the city and county. (Table)*

# Land Cover change from 2001 to 2011 in Memphis and Shelby County

| Land cover change (Percent) | | To 2011 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Developed | Barren | Forest | Herbaceous | Planted/ Cultivated | Shrub | Water | Wetland | sum |
| `From 2001 | Developed | 40.899 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 40.899 |
| | Barren | 0.060 | 0.142 | 0.000 | 0.001 | 0.001 | 0.000 | 0.006 | 0.000 | 0.209 |
| | Forest | 0.736 | 0.027 | 12.609 | 0.077 | 0.025 | 0.056 | 0.003 | 0.007 | 13.539 |
| | Herbaceous | 0.004 | 0.001 | 0.003 | 0.055 | 0.000 | 0.000 | 0.000 | 0.001 | 0.063 |
| | Planted/Cultivated | 2.065 | 0.033 | 0.044 | 0.010 | 23.835 | 0.044 | 0.053 | 0.093 | 26.178 |
| | Shrub | 0.292 | 0.020 | 0.039 | 0.017 | 0.010 | 4.574 | 0.003 | 0.008 | 4.963 |
| | Water | 0.048 | 0.049 | 0.001 | 0.002 | 0.006 | 0.016 | 4.565 | 0.023 | 4.711 |
| | Wetland | 0.185 | 0.004 | 0.001 | 0.003 | 0.002 | 0.002 | 0.009 | 9.233 | 9.438 |
| | sum | 44.288 | 0.276 | 12.698 | 0.164 | 23.878 | 4.692 | 4.638 | 9.365 | 100.000 |

“Planted/cultivated” is the largest proportion of land converted to “developed” or built-up land. Add forest, shrub land, herbaceous, and even wetland and water (0.64), then the proportion of “nature” to development is 1.74%. The significance of this value is realized as a proportion of total land area of the city and county.

# Land cover Transitions in Memphis and Shelby County Indicated by Shannon Index Change from 2001 to 2011




Note: land cover categories include: developed, barren, forest, herbaceous, planted/cultivated, shrub, water and wetland. (Source of Land Cover Data, NLCD)

# Land Use Mix vs. Diversity

To determine if the built-up or developed land, measured by entropy index, is a random pattern that is more or less diverse in land use we used Simpsons diversity index *D*, defined thus:

$D = 1 - \sum_i^n p_i^2$ .

It turns out that the entropy (Shannon) index of sprawl and Simpson index of land use diversity increase in tandem: land use that approximates sprawl i.e., close to entropy value of 1 is increasingly more diverse, close to Sampson index value of 1. For example, the regional public park (Shelby Farms park), shown to the east of interstate highway (I-240 loop) in the thematic map (Figure 2) of land cover transitions with entropy index value change < 0.2 has a similar diversity index value, since park/open space is the predominant land use.

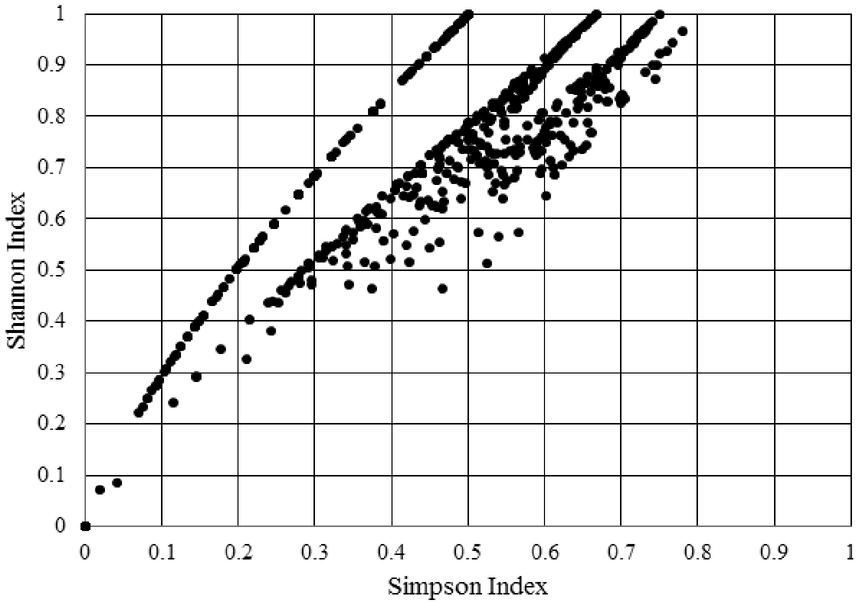
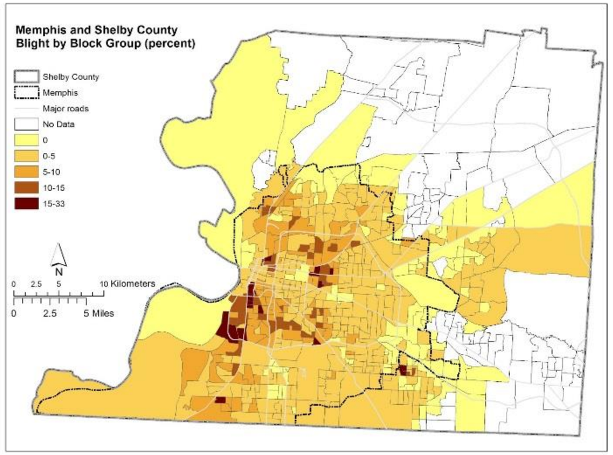



Figure 2. Simpson vs. Shannon relative index at built-up areas of Memphis and Shelby County, 2010

# Correlation of Sprawl and Blight

Wide-ranging, menacing social, economic, and environmental consequences of sprawl are recorded in a vast literature, including but not limited to regional (income) inequality, limiting regional mobility and accessibility to jobs and services, increasing public health consequences of limited walkability (physical inactivity, obesity) of an auto-centric urban form, increasing demand on city services and infrastructure outpacing ability of local government to supply services. However, in discussions of sprawl inadequate attention is given to the correlation of sprawl and blight. We set out to determine a relationship.




**Distribution of blighted area by block group in Memphis and Shelby County, 2016**
(Source of blight data: Bluff City Snapshot survey 2016)

# Correlation of Sprawl and Blight: Blight Depends on Sprawl

Regression between **Shannon relative index**, as independent variable x and **blighted area percentage** as dependent variable *y* = *f(x)* for block groups in Memphis and Shelby County and for 2016 is as follows:

$$y = 0.02647\, x^2 - 0.02444\, x + 0.009456$$

$R^2$ = 0.98; RMSE = 0.005159

# Correlation of Blight and Income

Discussions of sprawl and blight in literature include income (inequality). We used alternative measures of income in a statistical investigation of sprawl and blight. With **per capita income** *x* we find the best negative exponential fit.

*y=0.2024 e-0.0001631x*; $R^2$ = 0.9952; RMSE = 0.002977.
Coefficients with 95% CI, *a* = 0.2024 (0.1973, 0.2075), *b* = -0.0001631 (-0.0001657,-0.0001604)

Regression between **median income** (as independent variable) and **percentage of blighted area** (as dependent variable) for block groups in Memphis Shelby County and,2010 resulted in a similarly good fit ($R^2$= 0.9881).

# Correlations of Blight, Income, and Distance to Memphis CBD

If distance to city center (CBD) is an indicator of sprawl, then it is logical to assume that blight is a consequence of the sprawling metropolis “naturally” expanding outward while the declining infrastructure is left behind.

We observe that the incidence of blight measured by proportion of blighted properties per census block group *y* decreases exponentially with distance *x* from the city core.

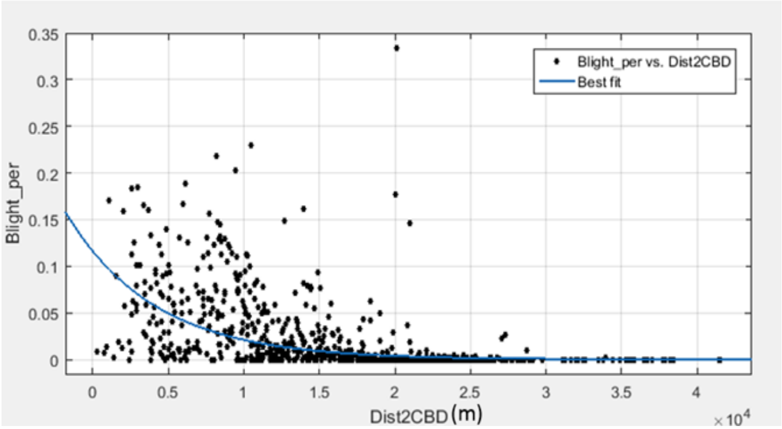
*y=0.1163 e-0.0001706x*

Coefficients with 95% confidence interval

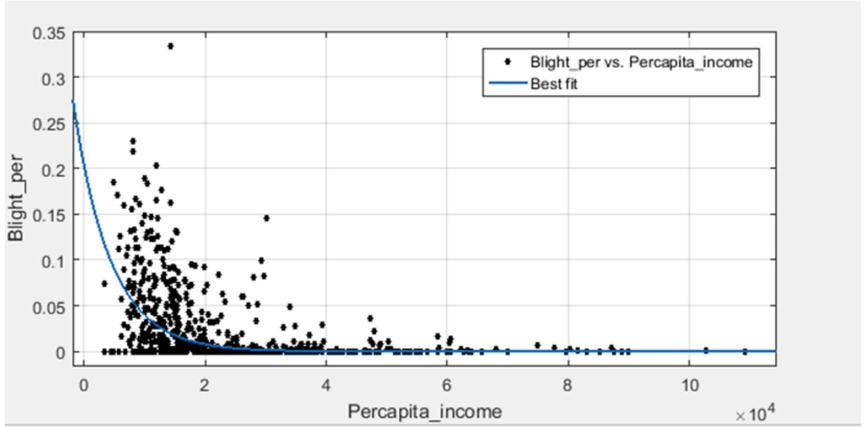
a = 0.1163 (0.1143, 0.1183)

b = -0.0001706 (-0.0001735, -0.0001677)

$R^2$ = 0.99   RMSE = 0.003306




The Decay of Blight in Block Group by Distance to Memphis CBD.




The decay of blight with income. Regression between per capita income (as independent variable) and blighted properties area percentage (as dependent variable) for block groups in Memphis and Shelby County 2016

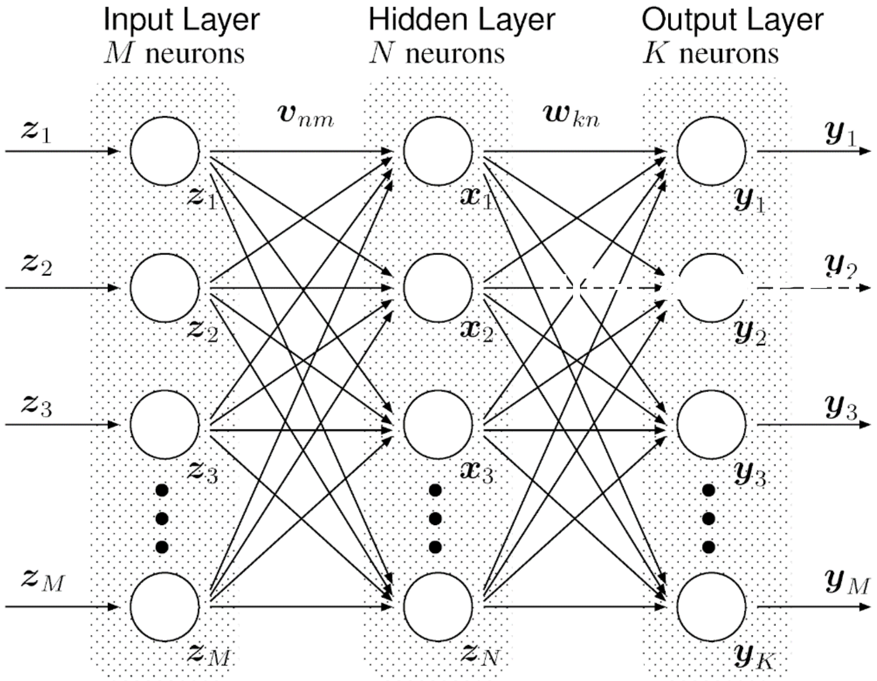
# II. A Geospatial Simulation Model of Land Use, Land Cover Change for the Memphis Metropolitan Region

Land use/land cover change (LUCC) is a critical element of urban growth pattern; hence also gauging future transitions that characterize smart urban development. The metropolitan region is vulnerable to the consequences of urban sprawl, particularly in the impervious, built-up areas in proximity to rivers, creeks, and wetlands posing the risk of local flooding during intensive-rain events in neighborhoods, damaging both ecosystem and property.

The longitudinal land use/cover inventory and conversion transitions facilitated by timely remote sensing and geospatial mapping technologies are a fundamental part of an evidence-based planning process that informs and guides environmentally sustainable future urban growth through comprehensive, long-term planning and zoning.

We used a modified version of Land Change Modeler (LCM) to run multi-layer perceptron (MLP) neural network algorithm in IDRISI's TerrSet Geospatial Monitoring and Modeling software originally developed by Clark lab, Clark University. The variables (or drivers) tested included land cover maps from National Land Cover Dataset (NLCD) compiled for years 1992, 2001 and 2011, demographic variables at census block group level for 2000 and 2010, road network for 1990, 2000, and 2010, housing and employment density for 2000 and 2010, and parks and open space for 2000 and 2010. Three development intensities (low, medium, high) were determined by percent of impervious area from NLCD and used as a response variable.

# Multi-Layer Perceptron (MLP)




**Potential drivers**

- Land-use mix (in developed areas) per census block
- Employment-to-residential worker ratio per census block
- Housing density
- Parks and open space
- Mode of transportation to work
- (% auto trips)
- Transit routes and stops
- Areas of natural constraints (growth deterrent): Floodways/Floodplains
- Major roads and highways

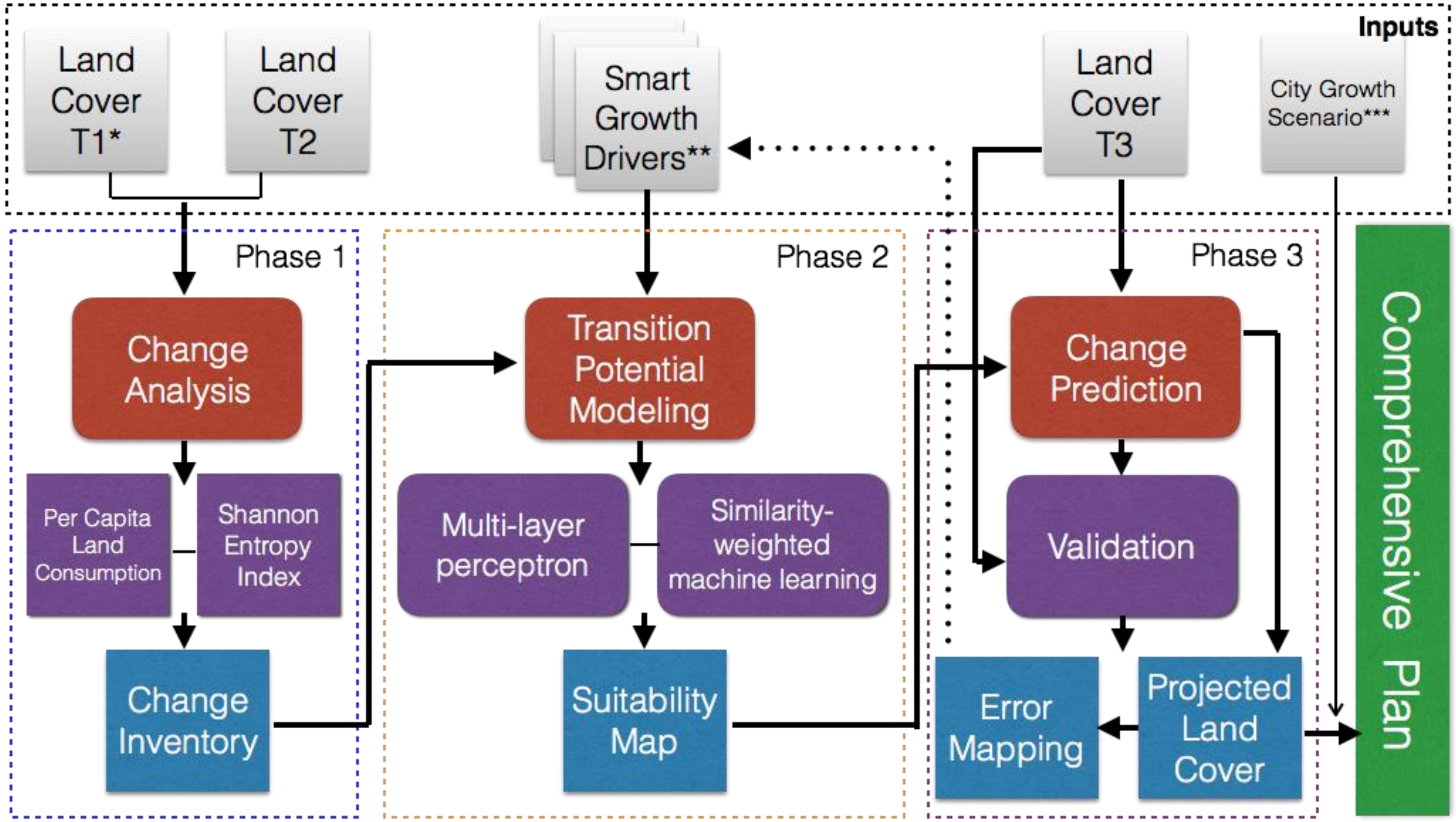
# Selected Drivers

Employment Density

Housing Density

Population Density

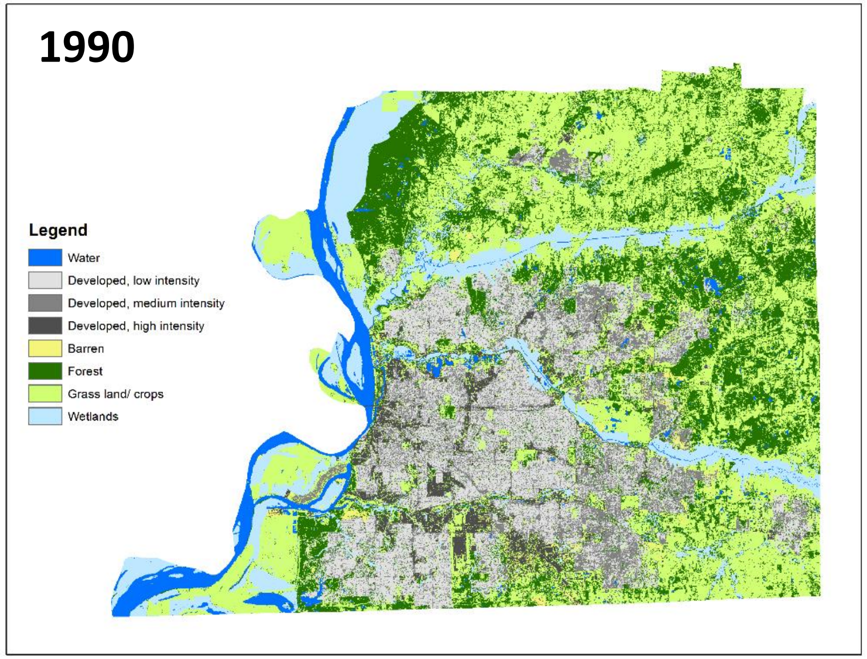
# Modeling Process

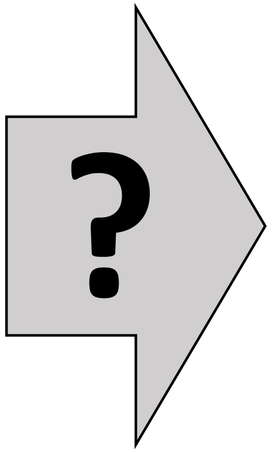


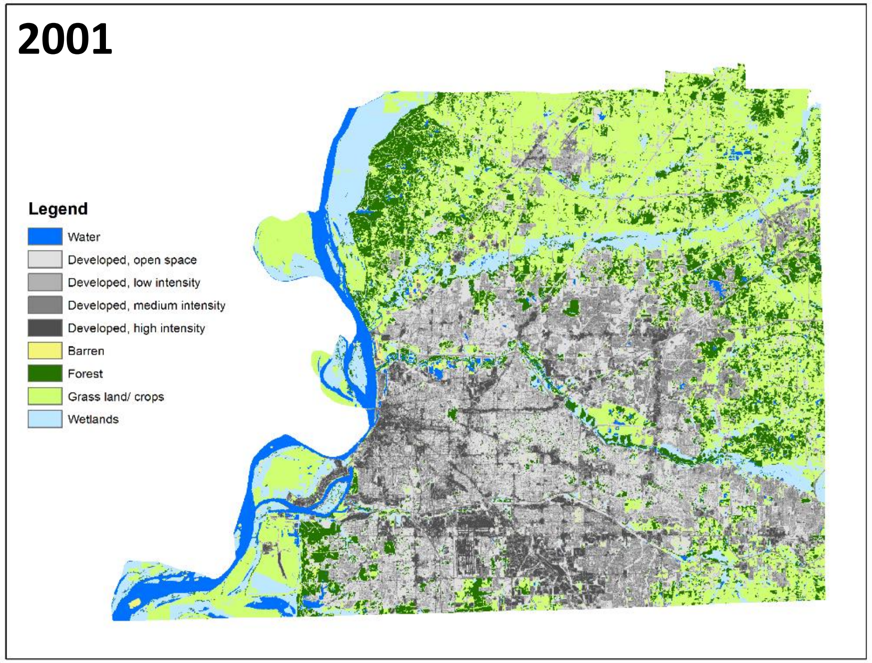

* Land cover T1 and T2 denotes land cover maps from year 1970 to 2010 at 10-year interval and T3 denotes the latest land cover map used for the model validation.
** Smart Growth Drivers include presence of multi-modal corridors (transit corridors), centers (urban and regional), districts (industrial; mixed use), and preserves (floodplain, floodway).
*** City Growth Scenario is from the 9-month visioning process by the city of Memphis under the New Comprehensive Plan

Geographic Information System (GIS) Applied to Phases of a New Comprehensive Planning Process for the City of Memphis.

# Modeling Transition Potential



# Land Use “Business as Usual” Projected to 2016 for Memphis and Shelby County


The prediction for year 2040 using business as usual scenario indicated that urbanized pattern consistently spreads outwards (eastwards) with noticeable new development along the road networks (I-385) and periphery of existing developed area.

# Further Research

We would like to examine further the forecasting accuracy of the GIS machine learning model in replicating observations for a known year, i.e., extrapolation vs. interpolation to 2040. Since housing density is determined as a significant driver, in a future study we plan to examine an alternative to BAU. Developing future scenarios that depart form BAU, for example, with housing weighted in favor of high density (smaller single family lots, multifamily, duplex) instead of low density single family housing that is prevalent in the Memphis region are plausible applications of the IDRISI- planning support system, with (re)zoning implications.

# Acknowledgments

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