IJNES International Journal of Natural and Engineering Sciences 2 (1): 09-19, 2008
ISSN: 1307-1149, www.nobel.gen.tr

Predicting Urban Growth in a US Metropolitan Area with No Zoning Regulation

Hakan OGUZ[1*] A.G. KLEIN[2] R. SRINIVASAN[3]

[1] Department of Industrial Engineering of Forestry, Faculty of Forestry, Kahramanmaras S. University, Kahramanmaras, 46100, TURKEY

[2] Geography Department, Texas A&M University, College Station, TX, 77843, USA

[3] Forest Science Department, Texas A&M University, College Station, TX, 77845, USA

[*] Corresponding Author
e-mail: hakan@ksu.edu.tr

Received: June 15, 2007
Accepted: September 15, 2007

Abstract

The Houston-Galveston-Brazoria Consolidated Metropolitan Statistical Area (Houston CMSA) has experienced rapid population growth during the past 3 decades and it is projected to reach approximately 7.5 million by 2030. Houston also is the only major US metropolitan area with no zoning regulations. Using SLEUTH, a spatially explicit cellular automata model, the spatial pattern of future urban growth within the Houston CMSA is predicted for the 2002 to 2030 period. The SLEUTH model is calibrated for local conditions in Houston using four historical urban extents, two land use layers, four transportation layers, slope layer, and excluded layer for the period from 1974 to 2002. The modeled SLEUTH, growth in the Houston CMSA is predominately "organic" with most growth occurring along the urban/rural fringe. Projected increases in urban area from 2002 to 2030 parallel projected increases in population growth within the Houston CMSA. From 1990 to 2000, the population of Houston CMSA more than doubled from approximately 2,000,000 to 4,600,000 and it is expected to grow by an additional 2,800,000 people by 2030. Secondly, urban growth in Houston over the past 30 years has epitomized the term urban sprawl because the urban area has quadrupled, growing from 941 to 3,724 km^2 from 1974 to 2002, and it is predicted to double by 2030, reaching 6,621 km^2.

Key words: Urban Growth, SLEUTH Model, GIS, Remote Sensing, Houston CMSA, Prediction.

INTRODUCTION

Urban planners and other academics focused their attention on urban growth models in order to help understand, and potentially lower the negative effects of large-scale urbanization. Planning agencies have recently been integrating analytical decision making tools with traditional planning approaches to improve planning for their communities. Technologically based tools such as urban models and geographic information systems (GIS) can provide insight into different growth scenarios, enabling policy makers to more effectively use traditional planning tools [11].

Sprawl has been in effect with the exurban growth in our cities. Middle-class and wealthy residents are drawn out of the inner city into the suburbs and exurbs [3, 10, and 15]. Higher taxes on farmland, demand for better public services, trespassing on farmlands, and displacement of farm families to the city are some of indirect impacts of exurban growth [4, 5, and 24].

Between 1900 and 1970 net migration in the USA was predominately from rural areas to urban centers [33]. Since then, the nation's rural population fluctuated between 50 and 60 million, while the urban population increased nearly sevenfold to approximately 150 million in 1970 [12]. During the 1970s, the trend of net migration to urban centers reversed with large cities losing population to non-metropolitan rural areas and small cities with populations less than 25,000 residents laying on the urban fringe [33]. The largest net population growth rates in the 1970s were in the non-metropolitan counties adjacent to at least one metropolitan county [16]. A metropolitan county contains a city with at least 50,000 people or is part of an urbanized metropolitan area with a population of at least 100,000 [22]. During the 1980's, the nation returned to the historical norm of rapid metropolitan population growth with net out-migration from rural areas to metropolitan areas [12]. However, population continued in non-metropolitan counties located adjacent to metropolitan ones [16].

Population dispersion from city centers to the outwards in the USA and in other industrialized nations has been facilitated by advances in transportation and communication technologies, changes in labor-force composition, increases in personal affluence, and a reduction in rural-urban differences [33, 12]. The lessening distance brought about by technological changes and by the expansion of transportation infrastructure has made rural landscapes in both metropolitan and adjacent non-metropolitan counties accessible for residential development.

During the last 50 years, these migration patterns to and within metropolitan areas in the United States have caused rapid growth, transforming farmland, wetland, and forests into extensive urban landscapes. Research scientists and policy makers are paying attention to the consequences of urbanization as a result of the environmental impacts it produces. The widespread expansion of urban areas has been especially evident in regions that are undergoing rapid economic development. In such areas, problems arise when urbanization is poorly planned. Unplanned and uncontrolled urbanization results in sprawl, conversion of prime agricultural land to urban uses, and habitat fragmentation.

Houston, Texas, is an example of rapid expansion of an urban area in the United States. The Houston-Galveston-Brazoria Consolidated Metropolitan Statistical Area (hereafter referred to as the Houston CMSA) is among the nation's most dynamic and rapidly growing metropolitan areas. Between 1900 and 2000, the region's population more than doubled growing from approximately 2,000,000 to 4,600,000 [29]. The population is projected to grow by an additional 2,800,000 by the year 2030 [23]. Because Houston's spatial growth over the past 30 years has been a prime example of urban sprawl and there is no reason to assume this growth mode will not continue in the future.

Any substantial increase in population usually has a negative effect on land because it requires the land, which is employed for other uses, to be converted to urban land. There has been a movement recently to develop urban simulation models that are designed to help understand the spatial expansion of urban areas [34, 6, 2, 8, 7, 25, 35 and 20]. These urban growth models follow in the long and distinguished tradition of the mapping and quantifying spatial patterns of urban growth [28]. Urban models have been developed to predict, describe, and analyze the spatial expansion of urban areas for research and policy purposes [19, 1, 18, 9, 14 and 17].

One of these new urban growth simulation models is the SLEUTH model. The acronym, SLEUTH, was compiled from the image input requirements of the model: Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade. The SLEUTH model has been designed for easy portability to diverse regions throughout regional and global scale and SLEUTH has successfully predicted urban expansion in the San Francisco Bay area, the Washington-Baltimore corridor and in Lisbon-Porto, Portugal [8, 7 and 26]. SLEUTH is currently being used to model urban growth in Chicago-Milwaukee, Portland-Vancouver, the Philadelphia-Wilmington and New York metropolitan areas [13]. The model's validity can be evaluated by its ability to generate realistic urban patterns useful for scenario planning and various types of regional analysis.

In this research, the objectives are to (1) model the spatial pattern of urban growth for Houston, (2) investigate the relationship between urban growth and population increases; and (3) predict urban growth for a period of 30 years.

Study Area

Houston, Texas, presents an ideal metropolitan area for modeling spatial patterns in urban growth using SLEUTH model. First, from 1990 to 2000, the population of Houston more than doubled from approximately 2,000,000 to 4,600,000 and it is expected to grow by an additional 2,800,000 people by 2030. Secondly, urban growth in Houston over the past 30 years has been epitomized by the term urban sprawl. The urban area has quadrupled; growing from 941 to 3724 km^2 from 1974 to 2002. Thirdly, compared to many other cities, urban expansion in Houston is largely unconfined. Outside of water bodies and floodplains, there are few physiographic limits to Houston's growth. Because Houston is the only major city without a formal zoning plan [32], urban growth there faces much less regulatory constraints than urban growth in many other cities in the United States.

Houston lies largely in the northern portion of the Gulf coastal plain along a 64 to 80 km. wide swath along the Texas Gulf Coast. The northern and eastern portions of the eight-county study area are largely forested, while the southern and western portions are predominantly prairie grassland. Perhaps the largest physiographic obstacle to growth in the Houston metropolitan area is surface water. The study area contains lakes, rivers, bays and an extensive system of bayous and manmade canals that are part of the rainwater runoff management system. Approximately 25%-30% of Harris County, which contains most of the city of Houston, lies within the 100-year flood plain.

The Houston-Galveston-Brazoria Consolidated Metropolitan Statistical Area (Houston CMSA) forms the basic areal unit of this study. The Houston CMSA (see Fig. 1) contains eight counties and three Primary Metropolitan Statistical Areas (PMSAs): The Houston PMSA encompasses Chambers, Fort Bend, Harris, Liberty, Montgomery, and Waller Counties while the much smaller Galveston-Texas City PMSA and Brazoria PMSA each comprise a single county, Galveston and Brazoria, respectively. The Houston CMSA's population of 4.8 million is the 10th largest among U.S. metropolitan statistical areas. The city of Houston has a population of 1.9 million and is the 4th most populous city in the nation trailing only New York, Los Angeles, and Chicago.

The City of Houston lies in three counties: Harris (1,511.13 km^2), Fort Bend (20.92 km^2), and Montgomery (6.73 km^2) (see Table 1). Under Texas' Municipal Annexation Act of 1963, the city of Houston (as can all cities over 100,000) also can exert certain powers over unincorporated areas lying within 8 km of any point on the city limits, which is termed the Extraterritorial Jurisdiction (ETJ). Houston's ETJ encompasses 3,397.93 km^2, excluding the area of cities that lie within it. In addition to Houston, Harris County contains part or all of 35 individual incorporated areas which lie outside of Houston's ETJ.

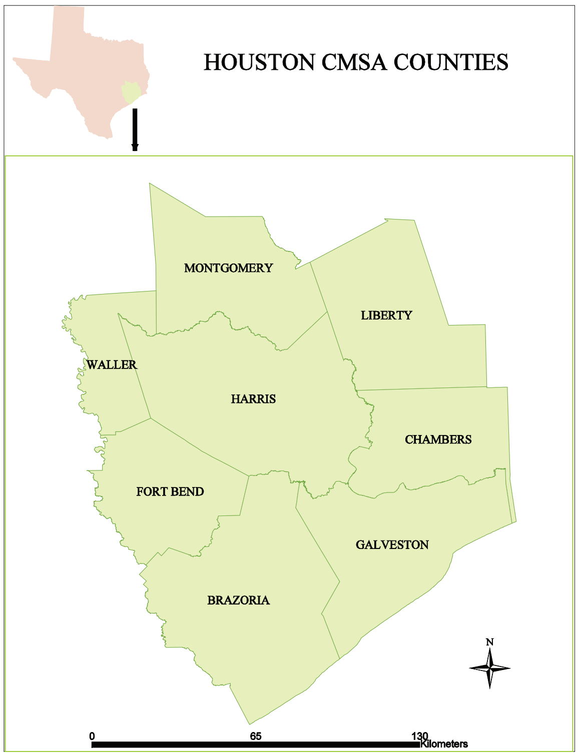

Figure 1. The Houston CMSA counties.

Table 1. Spatial extent of Metropolitan Statistical Areas and counties and the City of Houston.

NAME	AREA (km^2)
Houston CMSA	22,736
Houston PMSA	16,328
Brazoria PMSA	4,138
Galveston PMSA	2,270
Harris County	4,605
Chambers County	1,551
Fort Bend County	2,266
Liberty County	3,004
Montgomery County	2,704
Waller County	1,335
City of Houston	1,539

The City of Houston was founded in 1836 and incorporated in 1837, but grew slowly prior to 1900 when it reached a population of only 45,000. The Galveston Hurricane of 1900 and the discovery of large oil reserves at Spindletop in 1901, 145 kilometers east of Houston, led to Houston's rapid growth. Transportation improvements in the 19th and 20th centuries including the creation of the Houston Ship Channel which enabled oceangoing vessels to reach Houston itself also fueled Houston's growth. In the 20th century, federal and state intervention in the Houston economy expanded to include the funding of petrochemical plants, gas pipelines, refineries, and research and development in the petrochemical industry. The decision to locate the National Aeronautics and Space Administration (NASA) complex was another boost to the Houston area in the 1960s. [32] provides a good review of the factors fueling Houston's growth.

Population Growth and Urbanization

Globally, the world's population is becoming more urbanized. In 1995, 51 percent of the world's population lived in settlements of at least five thousand people, an increase of 29 percent from 1950 [7]. According to U.S. Census Bureau projections [30], which rely on assumptions about future fertility, mortality, and international migration rates, suggest a doubling of the U.S. population by 2100 to approximately 570 million people [31].

Texas's population has also increased dramatically since the 1960's, and in 2003 totaled approximately 22 million making Texas the 2nd most populous state after California [21 and 29].

Detailed population predictions for the period 2000 to 2040 have been performed on a county level basis for the state of Texas by the Texas Office of the State Demographer and The Department of Rural Sociology at Texas A&M University. These projections utilize a state of the art methodology cohort-component projection technique with existing demographic patterns taken into account [27]. Three population projection scenarios have been developed. The population projection used here represents the one-half 1990-2000 Migration scenario which assumes that net migration will occur at a rate one-half that observed during the 1990s. Table 2 below illustrates the population projections from 2005 to 2030 for each Houston CMSA county, Houston CMSA, and Houston PMSA [27].

Fig. 2 illustrates population projections for counties in the study area, excluding Harris for the 2005 - 2030 period. Fort Bend and Montgomery counties have the highest population among the seven counties and also they are projected to have the highest growth rate between 2005 and 2030. Chambers, Waller, and Liberty counties have low population amount and also have low growth rate relative to Fort Bend and Montgomery. Galveston also shows a trend close to send group, Chambers-Waller-Liberty, based on a lower growth rate especially after 2015.

Fig. 3 plots population growth for Harris county, Houston PMSA and Houston CMSA. Houston PMSA and Houston CMSA are similar in terms of their growth rate. This indicates that population is concentrated on Houston PMSA. Harris, Fort bend, and Montgomery counties have the highest population growth rate and population amount. Therefore, Houston PMSA shows parallel growth rate to Houston CMSA. The rest of the counties; such as Galveston, Waller, and Liberty; do not account much for the study area in terms of population growth and growth rate.

Population dynamics are important because land is required to accommodate the world's rapidly increasing urban population. In Texas, the major urban growth form is sprawl, occurring as a result of a surging state population.. Urban sprawl such as the one that has occurred in Houston is characterized by (1) low density development that extends outward from city centers, (2) a heavy dependence on automobiles for transportation and (3) single-use zoning that separates one type of land use from another [11]. As a result of urban sprawl, farmland and natural habitats are being replaced with low density single family dwellings and sprawling retail shopping complexes, deteriorating the environment and outpacing the economic

Table 2. Population projections from 2005 to 2030 for the Houston CMSA counties.

	2005	2010	2015	2020	2025	2030
Brazoria	263,631	285,850	308,656	331,731	354,258	375,664
Chamber	28,637	31,375	34,261	37,328	40,256	42,867
Fort Bend	401,710	449,811	501,218	557,407	615,222	670,032
Galveston	259,872	268,714	277,238	284,731	290,522	294,218
Harris	3,674,011	3,951,682	4,240,026	4,541,661	4,853,680	5,17,4691
Liberty	75,876	81,930	88,354	94,898	10,1220	107,335
Montgomery	335,176	379,363	426,858	478,187	531,570	585,111
Waller	36,644	41,137	46,142	51,175	56,654	62,352
Houston PSMA	4,552,054	4,935,298	5,336,859	5,760,656	6,198,602	6,642,388
Houston CMSA	5,075,557	5,489,862	5,922,753	6,377,118	6,843,382	7,312,270

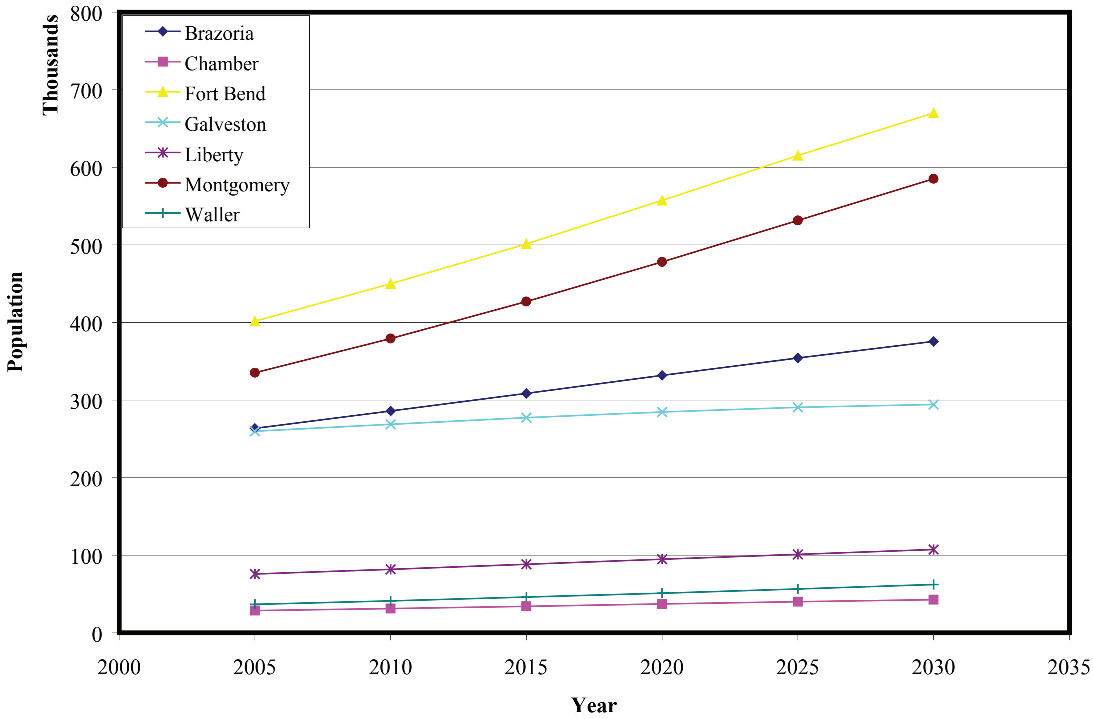

Figure 2. Population projections for counties in the study area, excluding Harris, for the 2005-2030 period.

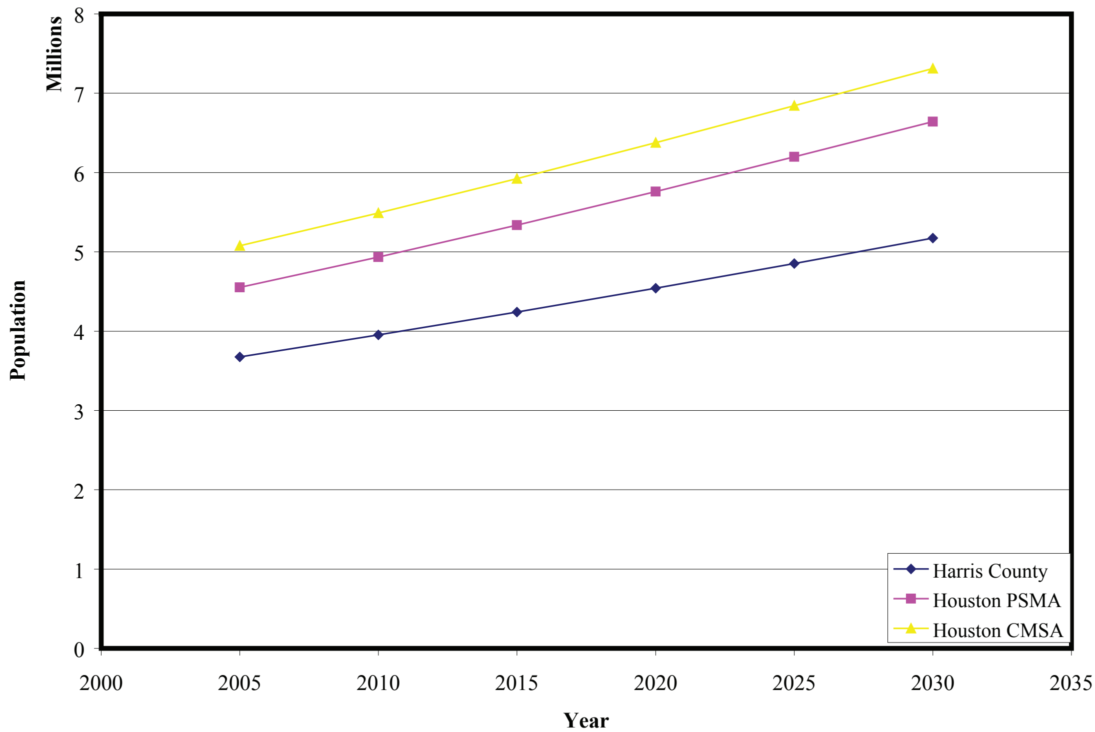

Figure 3. Population projections for Harris County and the Houston Primary (PMSA) and Consolidated (CMSA) Metropolitan Statistical Areas for the 2005-2030 period.

benefits of growth. As outlying growth centers continue to develop, such as Houston's edge cities of the Galleria and Greenspoint, people and businesses then begin to move away from the central city, which can lead to urban decay and the isolation of disadvantaged populations [11].

Urban modeling is generally concerned with designing, building and operating mathematical models of urban phenomena in order to help scientists understand urban phenomena through analysis and experiment and aid city planers, politicians and the community to predict future development [1]. According

Table 3. SLEUTH growth types [7]

SLEUTH GROWTH TYPES	DEFINITION OF GROWTH TYPES
Spontaneous Growth	Simulates the random urbanization of land
New Spreading Centers	Simulates the development of new urban areas
Edge (Organic) Growth	Stems from existing urban centers
Road-Influenced Growth	Simulates the influence of the transportation network on development patterns

to [14], the renewed urban models stem from two sources: (1) the power of personal computers and (2) the promise of geographical information systems (GIS). The role of models in the planning process has increased in relation to their greater acceptance in the planning community.

Urban areas have complex land use patterns. These complex urban patterns can be captured by GIS for use in models. [7] believe cellular automata (CA) models are ideally suited to modeling urban systems, because of more unknown than measurable variables. The number of variables involved in the urban growth process has not been concretely established. The SLEUTH model attempts to simplify the process by modeling the complex nature of urban areas solely by the physical controls to development.

MATERIALS AND METHODS

The Basics of the SLEUTH Model

The SLEUTH model, formerly known as the Clarke Cellular Automaton Urban Growth Model [7 and 8] is a CA model written in the C programming language and selected for predicting urban growth in the Houston CMSA. SLEUTH is an acronym created from its six required input layers: Slope, Land Use, Exclusion, Urban, Transportation, and Hillshade. SLEUTH model is also a probabilistic model that uses Monte Carlo routines to generate multiple simulations of growth. During calibration, each simulation is compared with the control years within the time series, and averaged fit statistics are produced to measure the performance of a set of coefficient values in reproducing the observed urban development patterns. The users can employ a single fit statistic, such as one that focuses on how well SLEUTH matches the rate of growth, or a set of fit statistics to define the model's performance, and then choose a set of parameter values that optimize the model's performance. This set of parameter values is used to predict historic patterns and rates of growth into the future. When predictions are produced, multiple simulations are run to create images showing the probability of any cell becoming urbanized over a series of annual time steps [13].

Four types of urban growth are possible in the model: 1) spontaneous, 2) new spreading center (diffusive), 3) organic (edge), and 4) road influenced growth (Table 3). Spontaneous growth occurs when a randomly chosen cell falls adjacent to an already urbanized cell. It simulates the influence urban areas have on their surroundings. New spreading center growth permits the urbanization of cells which are flat enough to be desirable locations for development, even if they are not located adjacent to established urban cells. Organic growth spreads outward from existing urban centers and represents the tendency of cities to expand. Road influenced growth encourages urbanized cells to develop along the road network. More detailed background on the model, please see [7] and [13].

SLEUTH Inputs

SLEUTH is a scale independent model and can be used to model the spatial patterns of urban growth at a variety of spatial scales in different regions. Successful initialization of SLUETH for the eight-county Houston CMSA requires five input layers: urban extent, transportation, areas to be excluded from urbanization (e.g., water bodies), slope and a hillshade image (for visualization only). For statistical purposes, model requires at least four urban extent layers. It also requires at least two transportation layers of different years, a single layer of slope, one layer with areas excluded from urbanization and a hillshade layer for use only as a background with the graphical version of the model [13]. A summary table of the SLEUTH inputs is described in Table 4.

The SLEUTH model domain for the eight county Houston CMSA study area (which is approximately 22,736 km^2.) was 1843 pixels east-west and 2100 pixels north-south. The spatial resolution of each grid cell in the model domain was 100 m x 100 m.

SLEUTH Calibration Results

We have successfully calibrated the SLEUTH model using historical urban extent, land use, and road layers. Table 5 shows coefficient values that were obtained in calibration phase. Five coefficients that control the behavior of growth are derived after the rigorous calibration process. These coefficient values are

Table 4. SLEUTH input dataset.

SLEUTH INPUT DATASET						
# of Layers	Layer Type	Years				
4	Urban	2002	1992	1984	1974	
2	Lulc	2002	1992			
5	Road	2025	2002	1990	1984	1974
1	Excluded					
1	Slope					
1	Hillshade					

Table 5. Averaged coefficient values after the "derive forecasting coefficients phase."

Year	Diffusion	Breed	Spread	Slope resistance	Road gravity
1984	1	2	84	36	15
1992	1	2	91	31	16
2002	1	3	100	23	17

used in prediction mode in the model to predict urban growth till 2030 for the study area, Houston CMSA.

The values that will be used in prediction mode are laid out in year 2002. As seen from the table above, spread coefficient is the single dominant coefficient, which states that the metropolitan area has been experiencing an "organic" growth.

RESULTS

The calibration process has resulted in the determination of a set of diffusion, breed, spread, slope resistance, and road gravity growth coefficients that enable SLEUTH to quite accurately simulate the observed growth in the Houston CMSA over the period 1974 to 2002. The successful calibration process also allows several conclusions concerning SLEUTH's ability to successfully model growth in the Houston Metropolitan area to be drawn.

The Lee-Sallee metric was chosen our primary goodness of fit measure in selecting the appropriate model runs throughout the calibration procedure. If the model grows in different ways or in different directions the Lee-Sallee will reflect that. The Lee-Sallee metric computed by comparing the SLEUTH predicted urban extent in 2002 obtained after final calibration to an independently derived remotely-sensed land use/land cover map was 0.51. Few published SLEUTH results include output statistics that can provide a context for our results. [26] modeled urban growth in Lisbon and Porto, Portugal using SLEUTH urban growth model. They achieved a Lee-Sallee value of 0.35 for Lisbon, and 0.58 for Porto. [7] achieved a Lee-Sallee value of 0.30, and they emphasized that even a 30 percent match was quite good for their study. Thus, it appears that the calibration process for Houston has been successful.

Future urban growth of the Houston CMSA is predicted from 2002 to 2030. The predicted growth is outputted individual years from 2003 to 2030. For this particular paper, predictions from only three years, 2010, 2020, and 2030 are illustrated in Figs. 4, 5, and 6 respectively.

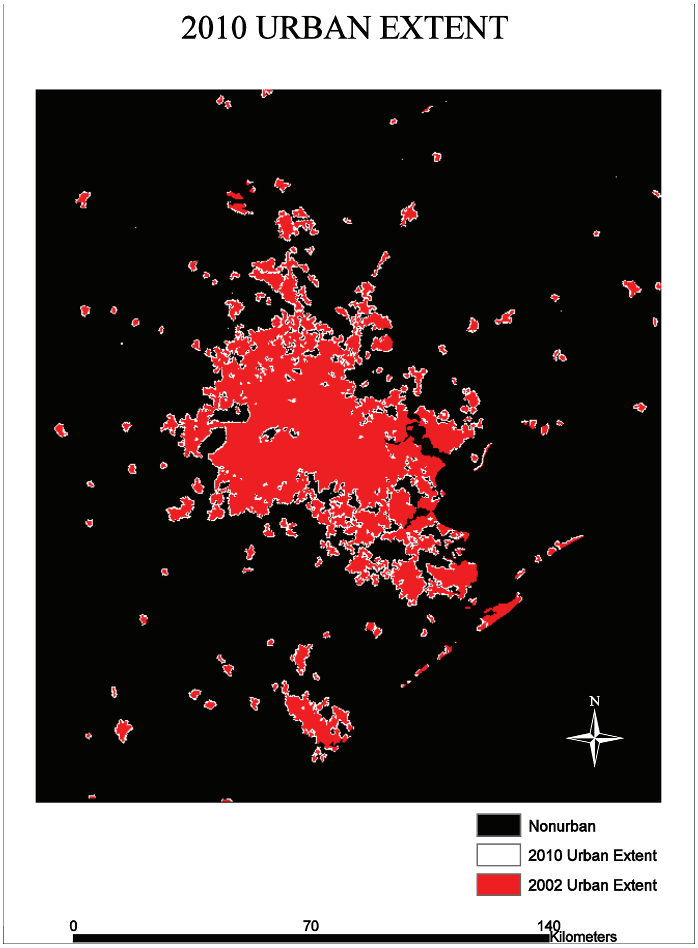

Figure 4. Predicted urban extent in 2010 for Houston CMSA.

2020 URBAN EXTENT

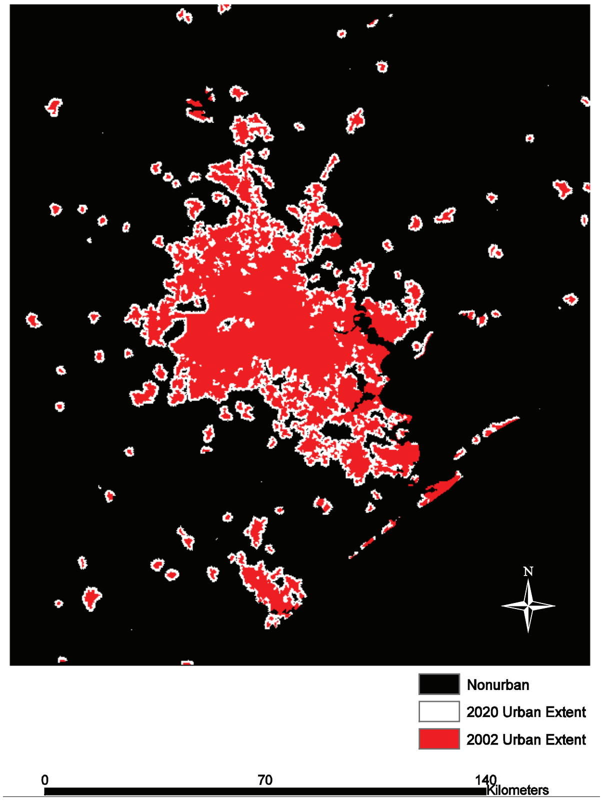

Figure 5. Predicted urban extent in 2020 for Houston CMSA

2030 URBAN EXTENT

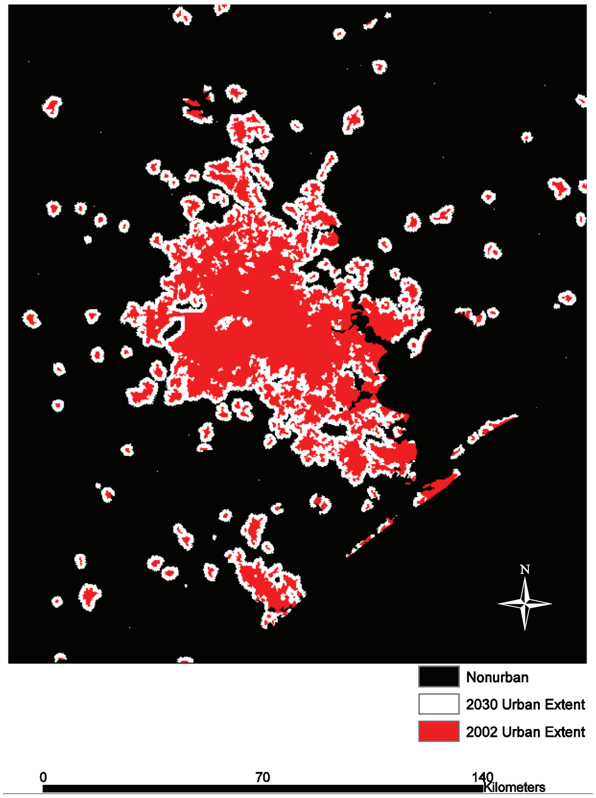

Figure 6. Predicted urban extent in 2030 for Houston CMSA.

The growth is concentrated on the urban-rural fringes and the calibration of the model helped us reach the best values. The model was accurate in modeling Houston CMSA's organic growth and this gives extra strength to the model's own ability to automatically calibrate itself.

Predicted population estimates [27] are used to compare with urban growth predictions. The results indicate that urban growth rate is slightly higher than population rate as shown in Fig. 7.

Past and future urban growth predictions in the three PMSAs that form Houston CMSA are presented in Fig. 8. It is easy to see that major urban growth occurs in Houston PMSA rather than other two PMSAs.

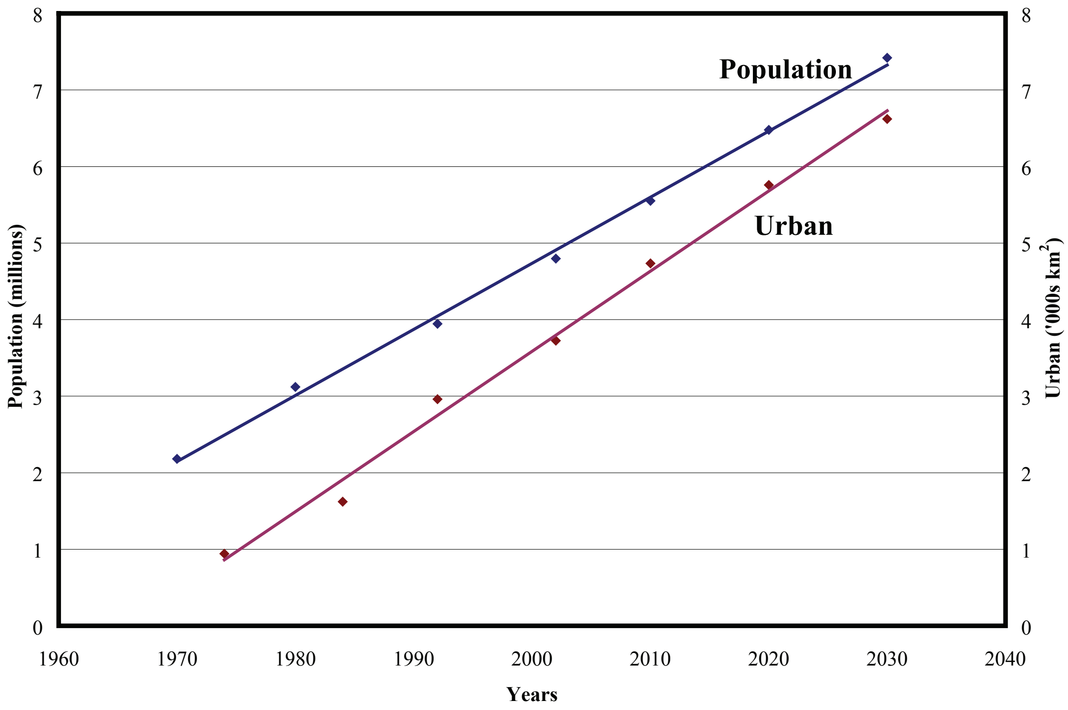

Figure 7. Population vs. urban growth in Houston CMSA.

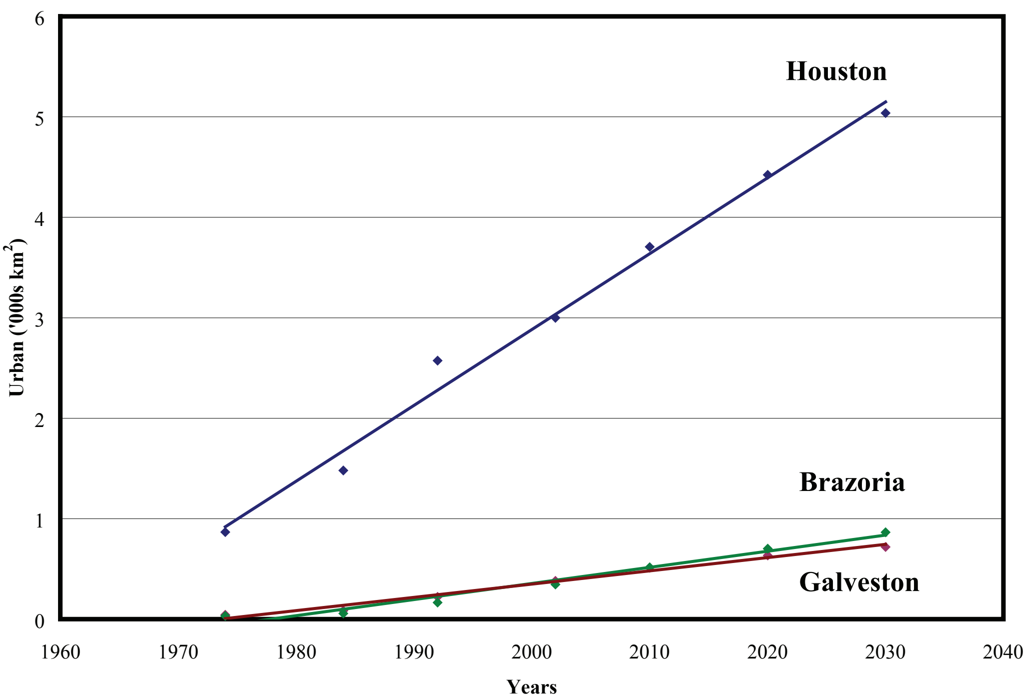

Figure 8. Urban growth in Houston, Galveston, and Brazoria PMSAs.

Urban growth by the percentage of land portion of county is a good measure to illustrate how much of the urban development account for the whole county area. Fig. 9 exhibits that Harris and Galveston counties account for most of the urban based on their county size.

Fig. 10 depicts an interesting result, such that, Harris and Galveston counties' growth rates have been in decline more than the other counties in Houston CMSA. This could be due to following two reasons: either growth rate is declining because available land also is declining for both of the counties, Harris and Galveston (see Fig. 9); or these two counties might have implemented a smart growth policy.

Fig. 11 illustrates the urban growth for each county, plotted in logarithmic scale. It is clear that Harris County is the most urbanized county in our study area.

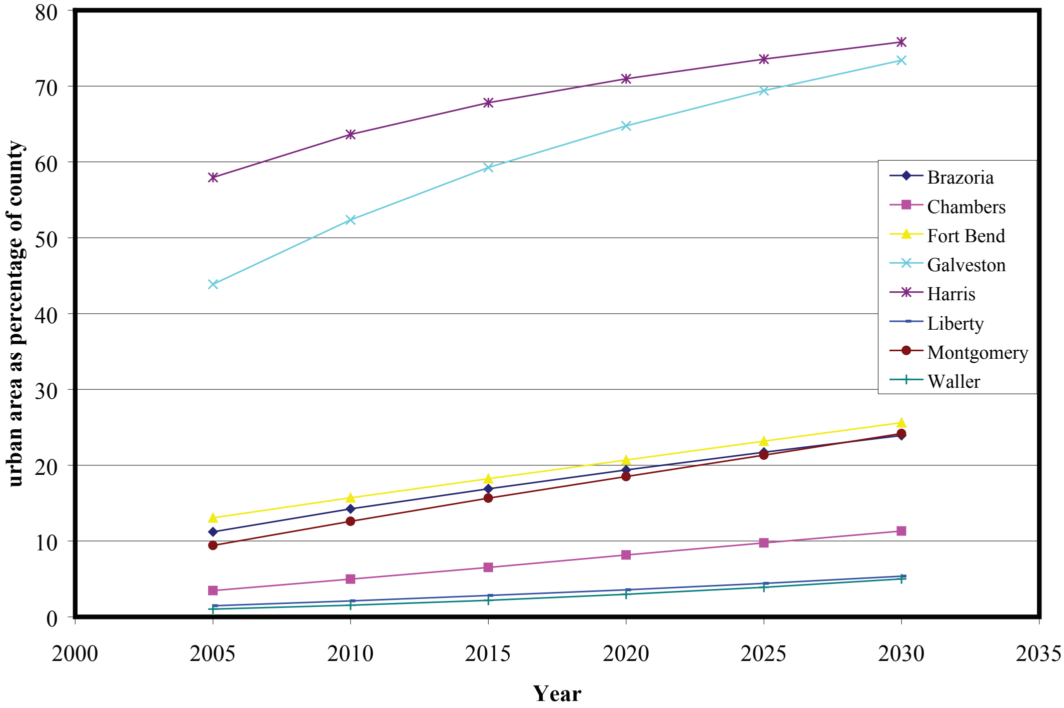

Figure 9. Urban area growth (% of Land portion of county).

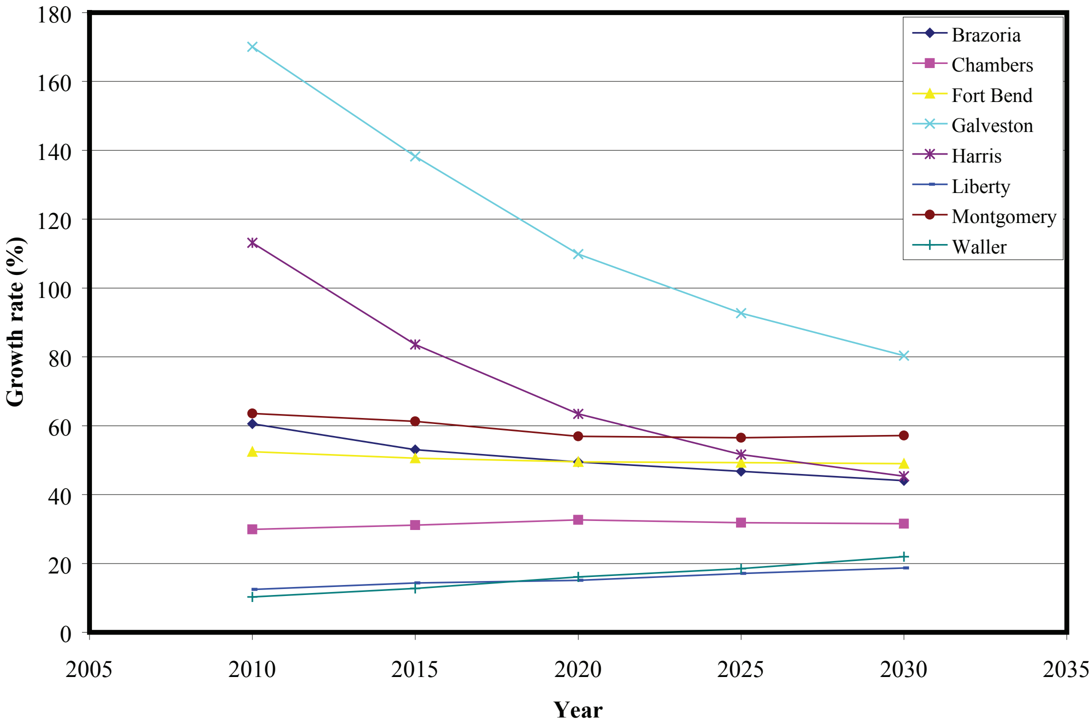

Figure 10. Growth rates [(year2-year1)/5] for CMSA counties.

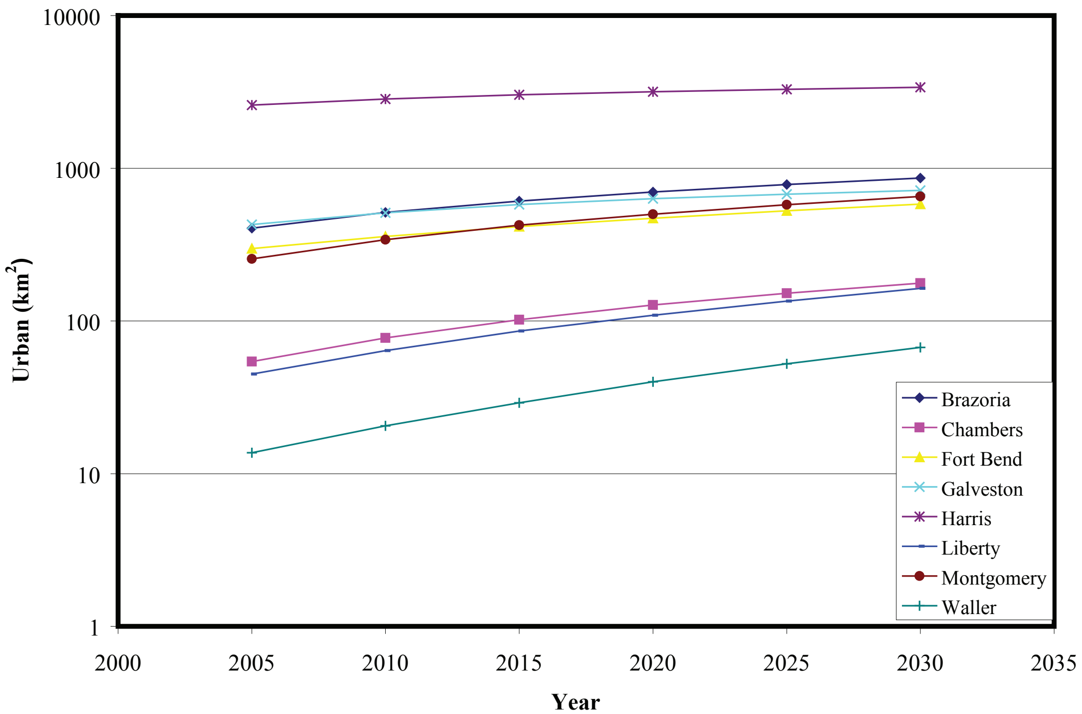

Figure 11. Urban growth in each county (logarithmic scale).

CONCLUSIONS

The uniqueness of this study is twofold: first, it is the only Consolidated Metropolitan Statistical Area that is modeled for urban growth and second, it is the only metropolitan area in the US that functions without formal zoning and a plan. Most increase in urban and population growth in Houston CMSA occurred between 1970s and 1990s. This trend however had slowed down in both urban and population by 2002. Results reveal that urban growth is concentrated on the urban/rural fringes in the Houston CMSA. Predicted results also indicate that urban growth for the period from 2002 to 2030 is in almost parallel with the population growth prediction.

Among Houston PMSAs, Houston was the major metropolitan area that drove the population and urban growth in Houston CMSA. Galveston and Brazoria PMSAs did not show increase in both and they reflect very small part of Houston CMSA.

Acknowledgements

Mr. Mark Feller from Rocky Mountain Mapping Center at USGS has run the calibration part for us on their AMD Athlon Beowulf PC Cluster. We appreciate all his help very much. Dr. John S. Jacob at Texas Coastal Watershed Program kindly provided Harris County Floodplain maps. Associate Professor and Extension Environmental Quality Specialist. Mr. Charles Dietzel, Ms. Jeannette Candau, Dr. Keith Clarke from University of California at Santa Barbara and Dr. Toby Carlson from Pennsylvania State University helped us during the model run. We also thank them very much for their unconditional support.

REFERENCES

[1] Batty M. 1976. Urban modeling: algorithms, calibrations, predictions. Cambridge: Cambridge University Press.

[2] Batty M, Couclelis H, Eichen M. 1997. Urban systems as cellular automata. Environment and Planning B: Planning and Design, 24(2), 159-305.

[3] Beale CL. 1977. The recent shift of United States population to non metropolitan areas, 1970-75. International Regional Science Review, 2, 113-122.

[4] Bryant CR. 1981. Agriculture in an urbanizing environment: a case study from the Paris region, 1968-1976. Canadian Geographer, XXV(1), 27-45.

[5] Bryant CR, Russwurm LH. 1979. The impact of non-farm development on agriculture: a synthesis. PLAN Canada, 19(2), 122-139.

[6] Cecchini A. 1996. Urban modeling by means of cellular automata: generalized urban automata with the help on-line (AUGH) model. Environment and Planning B: Planning and Design, 23(6), 721-723.

[7] Clarke K, Gaydos LJ. 1998. Loose coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Science, 12 (7), 699-714.

[8] Clarke, KC, Hoppen S, Gaydos L. 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environment and Planning B: Planning and Design, 24, 247-261.

[9] Couclelis H. 1997. From cellular automata to urban models: new principles for model development and implementation. Environment and Planning B: Planning and Design, 24, 165-174.

[10] Davies W. 1990. What population turnaround?: Some Canadian prairie settlement perspectives, 1971-1986. Geoforum, 21, 303-321.

[11] EPA - Environmental Protection Agency 2000. Projecting land use change: a summary of models for assessing the effects of community growth and change on land use patterns. EPA/600/R-00/098. Office of Research and Development, Cincinnati, OH. 260 p.

[12] Fuguitt GV, Brown DL, Beale CL. 1989. Rural and small town America. New York: Russell Sage Foundation. pp. 471.

[13] Gigalopolis 2006. Project Gigalopolis: Urban and land cover modeling. Santa Barbara, CA: University of Santa Barbara at http://www.ncgia.ucsb.edu/projects/gig/.

[14] Guhathakurta S. 1999. Urban modeling and contemporary planning theory: is there a common ground? Journal of Planning, Education and Research, 18(4), 281-292.

[15] Hodge G, Qadeer MH. 1983. *Small towns in Canada*. Toronto: Butterworth.

[16] Johnson K. 1989. Recent population redistribution trends in non-metropolitan America. Rural Sociology, 54, 301-326.

[17] Klosterman R. 2000. Operational urban models: a status report. Conference on Integrated Land Use and Environmental Models: A Survey of Current Applications and Research. Chicago, IL. October 20, 2000. pp. 199-223.

[18] Landis J. 1994. The California urban futures model: a new generation of metropolitan simulation models. Environment and Planning B: Planning and Design, 21, 399-420.

[19] Lee B. 1973. Requiem for large-scale models. Journal of the American Institute of Planners, 39(3), 163-178.

[20] Li X, Yeh A. G. 2000. Modeling sustainable urban development by the integration of constrained cellular automata and GIS. International Journal of Geographical Information Science. 14(2), 131-152.

[21] MERIC - Missouri Economic Research and Information Center 2003. Population Data Series. 2003 Population Estimates. MERIC at http://www.ded.mo.gov/business-/researchandpl-anning/indicators/population/pop2003.shtml.

[22] Myers D. 1992. Analysis with local census data: Portraits of change. San Diego, CA: Academic Press, pp. 369.

[23] Perryman Group 2002. The population growth in Houston CMSA from 1960 to 2000. Spring, 2002. Perryman Group at http://www.perrymangroup.com/.

[24] Rodd SR. 1976. The crisis of agricultural land in the Ontario countryside. PLAN Canada, 16(3), 160-170.

[25] Semboloni F. 1997. An urban and regional model based on cellular automata. Environment and Planning B: Planning and Design, 24(4), 589-612.

[26] Silva EA, Clarke KC. 2002. Calibration of the SLEUTH urban growth model for Lisbon and Porto, Spain. Computers, Environment and Urban Systems, 26, 525-552.

[27] Texas State Data Center 2003. 2000-2040 population projections for Texas counties. San Antonio: University of San Antonio. TSDC at http://txsdc.tamu.edu/tpepp/2001-_txpopprj_cntytotnum.php.

[28] Tobler WR. 1970. A computer movie simulating urban growth in the Detroit Region. Economic Geography, 26, 234-240.

[29] U.S. Census Bureau 2000a. Annual projections of the total resident population as of July 1: Middle, Lowest, Highest, and Zero International Migration Series, 1999 to 2100. Population Estimates Program, Population Division. Online, March 21, 2000. United States Census Bureau at http://www.census.gov/population/projections/nati-on/summary/np-t1.txt.

[30] U.S. Census Bureau 2000b. Population Change and Distribution. 1990 to 2000. Washington DC: United States Census Bureau at http://www.census.gov/prod-/2001pubs/c2kbr01-2.pdf.

[31] U.S. Census Bureau 2000c. Methodology and Assumptions for the Population Projections of the United States: 1999 to 2100. Population Division. Working Paper No 38. Online, December 20, 2000. Washington DC: Unites States Census Bureau at http://www.census.gov/population/projections/.

[32] Vojnovic I. 2003. Laissez-faire governance and the archetype laissez-faire city in the USA: exploring Houston. Geografiska Annaler, 85, B(1), 19-38.

[33] Wardwell JM., Brown DL. 1980. Population redistribution in the United States during the 1970s. In: D.L. Brown and J.M. Wardwell (Eds), New directions in urban-rural migration. New York: Academic Press, pp. 5-35.

[34] White R, Engelen G. 1993. Cellular automata and fractal urban form: a cellular modeling approach to the evolution of urban land-use patterns. Environment and Planning A, 25(8), 1175-1199.

[35] White R, Engelen G, Uljee L. 1997. The use of constrained cellular automata for high resolution modeling of urban land-use dynamics. Environment and Planning B: Planning and Design, 24(3), 323-343.