



Monitoring Small Area Growth with GIS – An Application to the City of Los Angeles

GIS를 이용한 소지역 성장 모니터링 기법 : 로스엔젤레스시 사례를 중심으로

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출처 (Source)	서울도시연구 9(4) , 2008.12, 145–164 (20 pages) Seoul Studies 9(4) , 2008.12, 145–164 (20 pages)
발행처 (Publisher)	서울연구원 The Seoul Institute
URL	http://www.dbpia.co.kr/Article/NODE02000112
APA Style	Seong–Youn Choi, Ping Wang, Elizabeth Delgado, Sung Ho Ryu, Kyuyoung Cho (2008). Monitoring Small Area Growth with GIS. 서울도시연구 , 9(4), 145–164.
이용정보 (Accessed)	University of Kansas(칸자스대학교) 129.237.***.81 2018/06/12 00:43 (KST)

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Monitoring Small Area Growth with GIS

- An Application to the City of Los Angeles -

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- 로스엔젤레스시 사례를 중심으로 -

최성연* · Ping Wang** · Elizabeth Delgado*** · 류성호**** · 조규영*****

ABSTRACT : This paper presents a technique of monitoring small area growth with GIS. Monitoring growth of small areas, including census tracts, blocks, or traffic analysis zones, becomes an important tool in measuring changes in small area plans(e.g., transit oriented development: TOD). Although geo-coded databases have become more popular and easily accessible in recent days, most available data is still spatially aggregated. The raster cell can be developed as a spatial base unit for monitoring small area growth. Spatially aggregated small area data is disaggregated into raster cells using land use information from both aerial photographs and local general plans. This study uses the land use weighted interpolation to develop uneven and more accurate distribution of the socioeconomic estimates within the census tract of the City of Los Angeles. This paper also discusses how to monitor the changing size and spatial distribution of small area household growth, specifically in and around the TOD areas. This study concludes that the raster cell approach toward developing socioeconomic estimates and forecast at the small area level might play an important role in making an efficient analysis and assessment of urban planning and policy, and requires further research.

Key Words : monitoring, small area growth, GIS, raster cell, city of Los Angeles

요약 : 본 연구에서는 GIS의 Raster Cell 방법을 이용하여 극소지역단위의 사회경제통계자료를 추정하고 극소지역의 성장을 모니터링하는 기법을 미국의 로스엔젤레스시에 적용한 것이다. 도시 및 지역계획의 수립과 정책결정을 제대로 수행하기 위해서는 소지역단위의 제반 사회경제통계자료가 구비되어 있어야 한다. 대부분의 소지역단위의 사회경제통계자료의 축성은 사실상 공간적으로 하나의 요약된 자료로 개발되었기 때문에, 매우 적은 극소지역(소지역권역)의 사회경제분석을 위해서는 매우 곤란한 경우가 많다. 이를 극복하기 위한 Area Interpolation 방법은 GIS의 기법으로서 소지역내의 극소지역단위의 사회경제통계의 추정시 중요한 역할을 한다. 면적에 따른 가중치를 적용하는 기법이 가장 광범위하게 적용되고 있다. 그러나 이 기법은 소지역내의 배분을 획일적으로 적용하는 점 때문에 극소지역의 정확한 사회경제

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자료를 추정할 수 없게 된다. 본 연구는 토지이용에 따른 가중치를 적용하는 방법을 이용하여 보다 정확한 극소지역의 사회경제통계치를 추정한다. 추정된 결과를 토대로 로스엔젤레스시의 성장을 격자단위의 극소지역 수준에서 모니터링을 하였으며, 최근 추진되고 있는 정책적 변화를 살피기 위하여 TOD지역에서의 변화와 장기계획 상에서의 변화를 모니터링할 수 있었다. Raster Cell을 이용한 극소지역단위의 사회경제자료 추정 및 예측은 효율적인 도시계획 및 정책의 분석 및 평가를 위하여 유용한 역할을 할 것이며, 보다 세밀한 연구가 수행될 필요가 있다.

주제어 : 모니터링, 극소지역의 성장, GIS, raster cell, 로스엔젤레스 시

I . Introduction

Urban and regional planning requires a variety of socioeconomic data at the small area level to do detailed analysis. The socioeconomic estimates at the small area play an important role in tracing the recent trends and figuring out the likely growth pattern of the small area. Those estimates are useful to assess the effectiveness of the policy and programs, or to evaluate the accuracy of the small area growth forecasts. Small area analysis is made possible with the effective use of the geographic information system(GIS).

The small area is not defined in a definite way, but in relative way(Smith and Morrison, 2005). Demographers might treat a county as a small area, the regional scientist might treat a metropolitan region as a small area, and transportation planner might a transportation analysis zone as a small area. The U.S. Census Bureau publishes socioeconomic data for a variety of small statistical areas. Even a census block, the smallest size of U.S. Census defined statistical areas, would be able to contain necessary socioeconomic data.

The nature of the available socioeconomic data for those small size statistical areas is spatially aggregated in a way that the socioeconomic data is

difficult to be used for the very small area analysis needed. For example, we might be interested in knowing the number of housing units within a certain distance(e.g., 1/4 miles or 1/3 miles) of the transit station/corridor, the number of jobs available within 30 minutes of the residence area, the number of low income households within a certain distance of the freeway, the number of residents living within a certain distance of the hazardous toxic facility or even how these variables change over time. How do we process socioeconomic data relevant to a specific very small area?

The area interpolation method plays a key role in determining the socioeconomic estimates of the small area. Area weighting have been widely used due to its easy applicability. This method, however, might not produce the accurate socioeconomic estimates because of its “even distribution” assumption. Recently, there have been some studies, the land use weighted interpolation method as of Reibel and Agrawal(2006), and Cho(2006) to reflect uneven and more accurate distribution of the socioeconomic estimates within the small area.

Thus this study aims to utilize the proposed method for monitoring growth of Los Angeles City. In other words, the study illustrates how socioeconomic data at the raster cell level would

be used to monitor the changing size and spatial distribution of small area housing growth, particularly, in and around transit oriented development areas.

II . Literature Review

The spatially aggregated socioeconomic data at the census tract level can be easily disaggregated into any small size zone using the area interpolation. The GIS analysis does not require developing a raster cell as a spatial unit base. The more accurate socioeconomic information at the smaller area level(e.g., raster cell), however, is expected to inform public policy, or to support business decision making(Smith and Morrison, 2005). GIS interpolation techniques are used to(whole or percentage) disaggregate the CT level households for buffer analysis related to TOD. Analysis of the growth within a certain distance of the station can be done using the method above.

The small area socioeconomic data of the U.S. Census can be easily summed to the large area socioeconomic data in many cases. The major problem occurs when the spatial analysis is needed for newly identified small areas, such as transportation analysis zones or neighborhood areas within a quarter mile distance of the train stations/ bus stops. Any interpolation techniques might not accurately depict the socioeconomic characteristics because of the data conversion process.

A better approach would be to use socioeconomic data of the smallest zone, which could be based on a “geo-coded” parcel(Mouden

and Hubner, 2000). The tax-lot parcel becomes an important unit of land information, data collection and analysis(Enger, 1992; Bollens, 1998). For example, we might be able to estimate the number of births and deaths for any different size of small area, if the birth or death data is available in a “geo-coded” parcel format. The Center for Demographic Research(CDR), California State University, Fullerton, annually estimates natural increase of each census tract of Orange County using geo-coded birth and death data. Geo-coded parcel data is the ideal unit of analysis and has become more useful and popular in recent days, but such data is expensive, hardly accessible, and limited in its scope.

The tax-lot parcel data contains the following land and building characteristics: acreage, land use, land value, improvement value, housing units, square footage, year built, bedrooms/bathrooms, amongst other factors. This information is conveniently available to the general public. For example, Los Angeles County Office of the Assessor developed the Property Assessment Information System (PAIS) to enhance internet services to the public¹⁾. The PAIS internet system is composed of four major elements: the parcel display(left-side base map showing individual parcels, street center lines, city and county borders), the parcel detail(right-side property information, recent sale information, roll values, property boundary description and building description), the assessor maps, and the recent sales.

Synthetic population is sometimes produced to meet the socioeconomic data needs at the very small area level. Due to confidentiality issues,

1) <http://maps.assessor.lacounty.gov/mapping/viewer.asp> accessed on April 29, 2007

some socioeconomic characteristics at the small area are not officially released through the public statistics agency, but need to be analyzed for planning and policy evaluation purposes. Several techniques including matching method, synthetic method, or Monte Carlo simulation are widely used in a variety of academic and practical fields (Clark and Holm, 1987).

The raster cell method can be an effective method in doing small area analysis and growth monitoring because of availability of land use image data from aerial photographs²⁾. The raster cell is used as a spatial unit base, and spatially aggregated small area socioeconomic data can be disaggregated into raster cells modeling current land use image data. For example, housing units may be reasonably estimated for each raster cell by processing land use image data using ArcMap Spatial Analyst and SAS(Cho, 2006). Landis and Zhang(1997) noted that(hectare based) raster cells might have both advantages and disadvantages as units of analysis. They are small enough to capture the detailed fabric of urban land used but large enough to avoid problems of data “noise.” And, since they are fixed, changes and trends across time can be easily identified. On the negative side, they lack physical or legal reality. Unlike parcels, they are not transacted. Nor are they directly regulated. Thus, they are not themselves the subject of development or redevelopment decisions³⁾.

1. Interpolation Methods

The estimates of the very small area(e.g., raster cell) are, oftentimes would be very useful to perform more accurate socioeconomic analysis. Area interpolation method plays a key role in determining the socioeconomic estimates of the small area. Interpolation is defined as the method of predicting unknown values using known values of neighboring locations⁴⁾. There are several interpolation methods(Cai, 2004; Reibel and Agrawal, 2006; Bourdier, 2006).

1) Area interpolation Method

An area interpolation method was mainly discussed by MacDougall(1976) and Goodchild and Lam(1980). This method involves the following three steps⁵⁾. The first step is to overlay target and source zones. The second step is to determine the proportion of each source zone that is assigned to each target zone. The third and last step is to apportion the total value of the attribute for each source zone to target zones according to the areal proportions. This method is being questioned because of its assumption of uniform density of the attribute within each zone(Cai, 2004; Reibel and Agrawal, 2006).

2) Intelligent Interpolation Method

As GIS and remotely-sensed satellite images become widely available, intelligent interpolation methods have been developed(Mennis and Hultgren, 2006; Mennis, 2003, 2002; Eicher and Brewer,

2) <http://data.geocomm.com/helpdesk/general.html>

3) http://www.ncgia.ucsb.edu/conf/landuse97/papers/landis_john/paper.html

4) <http://www.innovativegis.com/basis/primer/analysis.html>

5) <http://www.geog.ubc.ca/courses/klink/gis.notes/ncgia/u41.html>

2001; Fisher and Langford, 1995; Langford and Unwin, 1994; Goodchild et al., 1993). They use supplementary data such as satellite images or land use data in area interpolation to improve estimation accuracy (Sadahiro, 1999).

Dasymetric map seeks to display statistical surface data by exhaustively partitioning space into zones where the zone boundaries reflect the underlying statistical surface variation. The process of dasymetric mapping is the transformation of data from a set of arbitrary source zones to a dasymetric map via the overlay of the source zones with an ancillary data set. In practice, dasymetric mapping is often considered a particular type of areal interpolation technique where source zone data are excluded from certain classes in a categorical ancillary data set. Dasymetric mapping is applicable to a wide variety of tasks where the user seeks to refine spatially aggregated data, for example in estimating local population characteristics in areas where only coarser, regional resolution census data are available⁶).

Mennis and Hultgren (2006) applied the dasymetric mapping to disaggregate population count at the census tract level to smaller zones. The following is how they applied the dasymetric mapping to Delaware County, Pennsylvania⁷).

(1) population data was collected from the U.S. Census Bureau for the year 2000 at the tract level, there are 148 tracts. (2) the ancillary land cover data were derived from the U.S. Geological Survey National Land Cover Data (NLCD) program. These raster data were derived from 2001 Land sat ETM+ imagery. For the dasymetric mapping, these

data were smoothed using a majority filter and converted to vector format. This resulted in a vector data layer with 3,526 polygons. (3) the dasymetric mapping was applied using a 'containment' sampling method with no preset class densities and no regions. This procedure produced a new vector data layer with 4,745 polygons.

The regression modeling method is designed to estimate the dependent variables by using the estimated relationship between the independent variables and the dependent variable. Mugglin et al. (1999, 2000) used the regression method to include ancillary information for spatial interpolation and estimation. Land use weighted interpolation is proposed as a way of developing the raster cell data set (Reibel and Agrawal, 2006; Cho, 2006). The interpolation can be made using the ordinary least squares (OLS) regression method or the maximum likelihood (ML) method. The regression coefficients of each residential land use category were used as weight factor for estimating population or households. Reibel and Agrawal (2006) found that land use weight interpolation improved the accuracy of population estimates.

2. Small Area Estimates and Forecasts

Small area estimates are different from projections or forecasts. The difference is found because of different temporal and methodological aspects (Smith et al., 2001). Population estimates are generally used by demographers to refer to approximations of population size for current or past dates while population projection refers to an

6) <http://astro.temple.edu/~jmennis/research/dasymetric/index.htm>

7) <http://astro.temple.edu/~jmennis/research/dasymetric/dasycasestudy/dasycasestudy.htm>

approximation for a future date. Small area estimates are developed using a wide range of data sources. Federal, state, and local governments produce a variety of socioeconomic data estimates. Private vendors sometimes fill the gap the available data and data needs. Two major agencies are worth mentioning. They are U.S. Census Bureau and California Department of Finance (DOF). Both U.S. Census Bureau and California DOF produce such socioeconomic data estimates. Their estimates are important because they are widely used for government budgeting purposes and a wide range of socioeconomic analysis. Those estimates are oftentimes not enough to meet the data needs at the small area level. The small area estimates(e.g. census tract) are developed using the most recent census count(e.g., CTPP), census estimates, DOF estimates, aerial land use data, employment data from ES202, parcel level data from tax assessor's office, and building permits and demolitions. Private vendors play a major role in regularly processing and updating the data that is not available through federal and state agencies because they are not usually involved in developing the most recent update of the census tract level or below.

Small area forecasts at the raster cell level require a completely different model process than the estimation process because of much uncertainty of the future residential land use. The future residential land use of small areas is generally determined by the dynamics of housing demand and supply factors. The top down approach is most widely used. According to the top down approach, the large area's housing forecast is followed by the

small area's housing forecast. This approach is useful due to its easy applicability and flexibility.

The large area housing forecast generally focuses on housing demand factors, in particular, population projections. The methodology and assumptions of developing population projection and converting projected population into households become a key technical and policy discussion item. The small area housing forecast process allocates the large area's housing demands or needs into smaller areas by considering the supply factors of the small areas. The small area forecast and allocation methodology and assumptions determine the future housing forecasts of the small area.

There are small area forecast models using the raster cell as a spatial unit(Smith et al., 2001; Brail and Klosterman, 2001; Waddell and Ulfarsson, 2004). The widely used models are the rule-based model. The major advantage of the rule-based model is its easy applicability and flexibility. The following is a brief overview of these rule-based forecast models. California Urban Future Model I and II(CUF I and CUF II) are an urban growth and land use policy simulation model. CUF II, in particular, uses a raster data structure(Landis, 2001). The raster cell allocation of CUF II is primarily based on development probability(e.g., bid scores for development or redevelopment). This model was applied to the nine-county Association of Bay Area Governments region. The database included nearly 1.8 million grid-cells⁸⁾. The Urban Development Model(UDM) is an integrated land use and activity modeling system for very small areas(e.g., blocks and portions of blocks) used in the San Diego region(Smith et al.,

8) http://www.ncgia.ucsb.edu/conf/landuse97/papers/landis_john/paper.html

2001). UDM is a two-stage nested allocation model. The first stage is to project small area forecasts for 208 zones using the gravity model. The second step is to further allocate 208 zone forecasts into 30,000 very small areas. The allocation is based on two factors: accessibility weight and the very small areas' capacity to accommodate growth. The average number of people for each of 30,000 very small areas is approximately 280 as of April 2000. Subarea Allocation Model(SAM) is a small area growth forecast and allocation model for the Phoenix metropolitan area by the Maricopa Association of Governments(Walton et al., undated). SAM is used to design and evaluate alternative land use scenarios. The subarea allocation is rule-based model and driven by the site suitability scores, which are created using measures including highway proximity, proximity to urban development, neighboring "built" uses, development probability. The current grid cell sizes are 220 feet on a size, or approximately 1.11 acres, and they can vary in size depending on the planning scale. There are approximately 2 millions grid cells⁹⁾.

III. Data and Method

The City of Los Angeles is the largest city in the state of California and the second-largest in the United States with a population of 4 millions. The City spans 469.1 square miles(1214.9 square kilometers). The City has added more than 1 million people and 170,000 households for more than 25 years since 1980. The household growth is

much slower than its population growth. According to the most recent growth forecast(SCAG, 2007), the City is expected to add more than 200,000 households for the 20 year planning period. The City currently has 837 census tracts within the city boundary as of April 1, 2000. Some census tracts cross the city boundary to include the neighboring cities or unincorporated areas. If we develop a grid cell of a 100m x 100m, the number of the grid cells would reach 48,274.

The study produces four sets of socioeconomic data at the raster cell level(100m×100m) for further analysis, assuming that the Census Tract level data were given:

- i) 2000 household estimates at the raster cell level(based on the 2000 Census);
- ii) 2005 household estimates at the raster cell level(based on the Claritas household estimates as of January 1, 2006);
- iii) 2005 household estimates at the raster cell level(based on 2001 Regional Transportation Plan(RTP) Household Forecasts at the Census Tract level, 1997-2025);
- iv) 2025 household forecast at the raster cell level(based on 2001 RTP Household Forecasts at the Census Tract level, 1997-2025).

1. Data

The study is based on a variety of data sources. The following is a brief overview of the data sources.

9) [www.mag.maricopa.gov/archive/PUB/GIS/Subarea Allocation Model.pdf](http://www.mag.maricopa.gov/archive/PUB/GIS/Subarea_Allocation_Model.pdf)

1) Aerial Photography

SCAG has acquired a set of digital orthorectified photography for the entire region including Mexicali, Mexico. The information was done at a 1-meter resolution for the urban portions of the region which is equal to 9,133 square miles. The additional 29,000 square miles were done at 2 meter resolution.

2) Existing Land Use

In 2000, the Southern California Association of Governments(SCAG) developed a digital land use coverage of its urban areas. The database covers the entire SCAG region, approximately 38,500 square miles, including Mexicali, Mexico.

3) General Plan

City general plans are collected by SCAG from each local jurisdiction and are stored in computerized format in SCAG's Geographic Information System(GIS). General plans are constantly being updated by the individual cities. The land use in the general plan is classified according to the Anderson(1971) land cover classification system. To make the modeling process more manageable, SCAG collapsed the 100-plus land use categories into seven: (i) undeveloped; (ii) single-family residential; (iii) multi-family residential; (iv) commercial; (v) industrial; (vi) transportation; and (vii) public.

4) Census Tract Level Household Forecasts
(7/1/2000, 7/1/ 2005, and 7/1/2025)

SCAG updates the growth forecast every three

or four years. SCAG Regional Council adopted a regional forecast, starting from 1997 to 2025, as part of the 2001 Regional Transportation Plan (RTP), in April 2001. The 2001 RTP growth forecast was developed in five year intervals between 2000 and 2025.

5) Claritas Tract Level Household Estimates
(1/1/2006)

Claritas, a private vendor, has produced the updated demographic data every year for more than 30 years. Tract Level Estimates are developed for January 1, 2006 by incorporating many data sources. The data sources contributing to the 2006 tract level estimates are: estimates produced by local governments or planning agencies, counts of deliverable addresses from the U.S. Postal Service, household counts from the Equifax Total Source consumer database, as well as counts from the Claritas Master Address List.

6) Census Tract Level Household Estimates
(4/1/2000)

The U.S. Census Bureau produces population and housing unit totals for Census 2000 at the census tract level. A census tract is a small, relatively permanent statistical subdivision of a county or statistically equivalent entity, delineated for data presentation purposes. Census tracts generally contain between 1,000 and 8,000 people¹⁰⁾.

7) Residential Building Permits for the City of Los Angeles(1/1/2001-12/31/2005)

The City of Los Angeles Planning Department

10) <http://www.census.gov/mso/www/c2000basics/00Basics.pdf>

keeps the recent residential building permits issued between January 1, 2000 and December 31, 2005 for single- and multiple-family housing units. This data is organized in the format of X/Y coordinates and linked to the 2000 census tract.

2. Raster Cell Household Estimates for Year 2000

Households at the raster cell level are estimated using the following equation:

$$Household_i^e = \varpi_r \alpha_k K_i$$

where $Household_i^e$ = household estimates of the raster cell i ,

ϖ_r = a locally weighted factor for census tract r where the raster cell i belongs to,

α_k = estimated global coefficient for the land use k ,

$K_i = 1$ if the land use of the raster cell i is k , otherwise 0.

The locally weighted factor (ϖ_r) is estimated to control the total household counts of all raster cells within the census tract r for the 2000 census household counts ($Household_r$) of the census tract r . It can be derived using the following equation:

$$\varpi_r = \frac{household_r}{\sum_k \sum_{i \Rightarrow r} \alpha_k K_i}$$

The land use weight (α_k) is derived using the maximum likelihood (ML) method. The census tract is used as a unit of analysis. The ordinary least squares (OLS) regression method produces a similar

coefficient. The global coefficients of each land use category are used as the weight factors, and they are estimated using the following regression model.

$$\begin{aligned} household_r = & \alpha_k^1 area_{1111} + \alpha_k^2 area_{1112} + \alpha_k^3 area_{1121} \\ & + \alpha_k^4 area_{1122} + \alpha_k^5 area_{1123} + \alpha_k^6 area_{1124} + \alpha_k^7 area_{1125} \\ & + \alpha_k^8 area_{1131} + \alpha_k^9 area_{1132} + \alpha_k^{10} area_{1140} + \alpha_k^{11} area_{1151} \\ & + \alpha_k^{12} area_{1152} \end{aligned}$$

where $Household_r$ is the 2000 census household counts of the census tract r , a subscript with area denotes land use code, and the unit of area is 10,000 m²,

area_1111: area of the high-density single family residential land use,

area_1112: area of the low-density single family residential land use,

area_1121: area of the mixed multi-family residential land use,

area_1122: area of the duplexes, triplexes, and 2 or 3 unit condominiums and townhouses land use,

area_1123: area of the low-rise apartments, condominiums, and townhouses land use,

area_1124: area of the medium-rise apartments and condominiums land use,

area_1125: area of the high-rise apartments and condominiums land use,

area_1131: area of the trailer parks and mobile home courts, high density land use,

area_1132: area of the mobile home courts and subdivisions, low density land use,

area_1140: area of the mixed residential land use,

area_1151: area of the rural residential, high-density land use,

area_1152: area of the rural residential, low-density land use.

Both the ML method and OLS method indicate that most of land uses had a statistically significant association with household estimates of the census tract ($\alpha < 0.05$). R^2 of the OLS is 0.8605 (adjusted R^2 is 0.8601). Only one land use category (area_1122: duplexes, triplexes, and 2 or 3 unit condominiums and townhouses) shows poor results. The coefficient of Area_1123 is assigned to area_1122. This study uses ML coefficients for application.

The process of developing a raster cell household estimate for year 2000 is as follows:

- 1) Estimate global coefficients (α_k)
 - (1) Union the land use and the census tract boundary
 - (2) Calculate “new area”
 - (3) Summarize the new area by the census tract and by the land use category
 - (4) Merge the result of (3) with the 2000 census household estimates
 - (5) Convert the land use categories to households using the estimated global coefficients of the ML method.
- 2) Normalize the global coefficients to control for 2000 census tract estimates (ϖ_r, α_k)
 - (1) Create a raster map (100m×100m grid) for each land use category by assigning value 1 and repeat calculation for every land use category.
 - (2) Multiply the coefficient of 1) by the

Table 1. Estimated coefficients from an OLS regression and ML method¹¹⁾

Variable	OLS Coefficient (t-statistics)	ML Coefficient (t-statistics)
Area_1111	8.49(77.15*)	8.49(77.23*)
Area_1112	0.54(3.09*)	0.54(3.09*)
Area_1121	54.60(14.51**)	54.55(14.52**)
Area_1122 ^a		
Area_1123	40.20(57.67**)	40.23(57.73**)
Area_1124	84.90(19.07**)	84.94(19.10**)
Area_1125	168.90(9.37**)	168.90(9.38**)
Area_1131	11.60(9.44**)	11.62(9.48**)
Area_1132	8.26(3.02**)	8.26(3.02**)
Area_1140	37.70(35.71**)	37.69(35.76**)
Area_1151	4.92(3.75**)	5.33(3.84**)
Area_1152	0.92(9.13**)	0.91(9.04**)

Source: Cho, K., *Work Book*, SCAG, 2006.

Note: 1) OLS good-of-fit statistics: F-statistics is 2.297.59 with 11 df: R^2 is 0.8605 (adjusted R^2 is 0.8601): The number of observations is 4,109;

2) ML Method good-of-fit statistics: -2 Log Likelihood is 63,801.2: AIC is 63,825.2: AICC is 63,825.3: BIC is 63,901.0: The number of observations is 4,109;

^a Omitted due to a poor estimation. The coefficient value of 40.2 was assigned for the analysis.

** $p < 0.01$ * $p < 0.05$

equivalent land category in the raster map above and repeat calculation for every land use category.

- (3) Mosaic all household related maps of (2)
- (4) Produce “zonal statistics” by census tract.
- (5) Create raster maps by using the sum of (4)
- (6) Create probability maps by using the map algebra [(2)/(5)]. Use the “raster calculator.”

3) Generate Raster Maps (ϖ_r, α_k, K_i)

- (1) Create a raster map (100m×100m grid) with

11) A review referee mentioned that some of the parameters might be unreasonable. Though it should be scrutinized, authors leave it for later studies for two reasons: 1) these parameters are used for the initial assignment for the population estimates and normalized later as in the equation; and 2) Area_1112 represents the low-density single family residential land use for mostly large-squared wealthy residents. The density might be even smaller than that of the rural residential land use.

Table 2. The allocation priority of household growth within a census tract

Allocation Priority	Development Type	Current Land Use (a)	Planned Land Use (b)	Residential Density (c)	Percent of Developable Land (d)
A	New development	Vacant	Residential area by density	Highest of the density range for residential area by type	100%
B	Infill or redevelopment	Residential	Residential	Highest of the medium density(55 housing units per acre)	30%
C	Land use change	Industrial, commercial	Residential, industrial, commercial	Highest of the medium density(55 housing units per acre)	30%

Note: Open space and other environmentally sensitive land are excluded from additional household growth.

the census tract household data.

- (2) Multiply (3) of 2) by (6) of 2) using the “raster calculator.”

3. Raster Cell Household Forecasts, 2005 & 2025

The household forecasts at the census tract level are allocated into the smaller raster cells using the following allocation rule. The allocation rule is developed by considering development potential. Development potential of each raster cell within a census tract is based on the capacity of the raster to accommodate additional household growth. The additional capacity of household growth of each raster cell is based on the following four factors (see table 2): (a) current land use, (b) planned land use, (c) residential density, and (d) percent of developable land.

This study categorizes the current seven land use categories(e.g., undeveloped, single-family residential, multi-family residential, commercial, industrial, transportation, and public) into four: vacant; residential; commercial/industrial; and other land use unsuitable for development.

The future land use plan specifies both land available and land not available for urban development and redevelopment during the planning period(Berke et al., 2006). After removing areas unsuitable for residential development, each raster cell is decomposed into three major land development categories: (1) residentially developable vacant land, (2) residential infill/redevelopment, (3) industrial or commercial land. The process of allocating census tract households into raster cell is as follows(see table 2):

- (1) Computing the maximum household growth capacity of residentially developable vacant land: The maximum household growth capacity of residentially developable vacant land is computed by multiplying each residentially developable vacant land by maximum household density allowed in the general plan of the City of Los Angeles.
- (2) Computing the additional household growth capacity of infill/redevelopment land: The additional household growth capacity of infill/redevelopment land is computed by multiplying 30% of existing residential areas

by maximum household density of the medium density residential areas allowed in the general plan of the City of Los Angeles.

- (3) Computing the additional household growth capacity of industry and office land uses: The additional household growth capacity of industry and office land uses is computed by multiplying 30% of existing industry and office area by maximum household density of the medium density residential areas allowed in the general plan of the City of Los Angeles.

IV. Results and Discussion

Since small area estimates and forecasts are easily accessible at the census tract level, small area growth can be easily monitored at the census tract level. The Gini concentration ratio can be calculated to measure the degree of inequality of two distributions (McKibben and Faust, 2004; Murdock and Ellis, 1991; Murdock et al., 2006). The Gini concentration ratio falls between 0 and 1. A Gini concentration ratio of 1 indicates complete inequality, with all households located in one locality. The Gini concentration ratio was calculated using household estimates and forecasts for the census tract level and five different categories of census tracts. The Gini concentration ratio ranges from 0.1902 for 2025 household forecasts to 0.2287 for 2005 household estimates. The recent housing growth pattern indicates that there is no significant change in the distribution of households between 2000 and 2005. However, two household

estimates from 2000 and 2005 are more unequally distributed than that of household forecasts for 2005 and 2025 from 2001 RTP household forecasts. This implies that the 2001 RTP household forecasts for 2005 and 2025 were designed to improve the equality distribution than that of 2000 households by promoting more growth of the census tracts with less than 1,000 households, but in reality the more equal distribution of households at the census tract level did not happen between 2000 and 2005.

The land use weighted interpolation method produced four sets of raster cell household estimates and forecasts for 2000, 2005, and 2025. (See Figures 1, 2, 3 and 4). The raster cell data was controlled for the census tract level data. The raster cell household growth was tabulated by three growth types (2000-2005(actual), 2000-2005(forecast), 2000-2025(forecast)) and by the proximity to a transit station¹²⁾(See table 4). The results indicate that the recent relative household growth within 1/3 mile of a transit station exceeds that of 2001 RTP household forecast within the same area between 2000-2005 and 2000-2025. Total estimated(actual) household growth between 2000 and 2005 within the 1/3 mile of the transit station accounts for 22.4% of total city wide estimated household growth during the same period, while total forecast household growth between 2000 and 2005 within the 1/3 mile of the transit station represents 10.1% of total city wide forecast household growth during the same period (See Table 4, Figures 3 and 4).

The recent pattern of relatively fast household

12) A transit station in the study would be one of 452 stations and stops (55 commuter rail stations, 122 light rail stations, and 275 rapid bus stops) in the SCAG region.

Table 3. Distribution of Households by Size of Census Tract and the Gini Concentration Ratio

Households by Size of Census Tract	Number of Census Tracts as of 4/1/2000	Number of Households			
		2000*	2005**	2005***	2025***
2,501 +	79	243,247	259,824	242,984	294,209
2,001 - 2,500	84	186,545	195,962	192,927	251,293
1,501 - 2,000	187	321,853	337,224	328,604	433,444
1,001 - 1,500	307	383,233	402,496	395,585	533,615
0 - 1,000	180	141,571	147,917	152,667	222,390
All Census Tracts	837	1,276,449	1,343,423	1,312,767	1,734,951
Gini Concentration Ratio		0.2260	0.2287	0.2165	0.1902

Source: * US Census Bureau, 2000 Census Household Estimates: ** Claritas 2006 Household Estimates: *** SCAG, 2001 RTP Household Forecasts, April 2001.

Table 4. Distribution of household growth by the Proximity to a Transit Station

Proximity to a Transit Station (in mile)	2000-2005 (actual)	2000-2005 (forecast)	2000-2025 (forecast)
0-1/4 mile	12.7%	5.5%	10.0%
1/4-1/3 mile	9.7%	4.6%	7.7%
1/3-1/2 mile	18.4%	15.0%	15.9%
1/2+mile	59.2%	74.9%	66.3%
Clustered Raster Cells	100.0%	100.0%	100.0%

growth within walking distance from the transit stations has two implications. The first implication is that the small area growth can be used to update the household forecasts in the coming years. More growth could be allocated into areas experiencing fast growth. The second implication is that the small area growth within walking distance of stations is attributed to strategic local and regional policies. The City's multi-pronged efforts and SCAG's Compass Blueprint Program focus growth in existing and emerging centers and along major transportation corridors. The City has implemented a transit vision strategy which has been followed by major policy shifts and infrastructure investments. At a regional level, SCAG adopted and is currently implementing the Compass Blueprint Program whose proactive approach to

planning and managing growth will create the types of communities where all of us want to live work and play by providing tools and services (such as fly through simulations and economic development strategies) to cities and counties throughout Southern California to realize this growth vision on-the-ground. The use of small area growth monitoring and the raster cell method in this paper provides the opportunity to tell a story behind the possible scenarios to policy-makers of the impact that future investments and policies can impact the makeup and character of the City and the region at large.

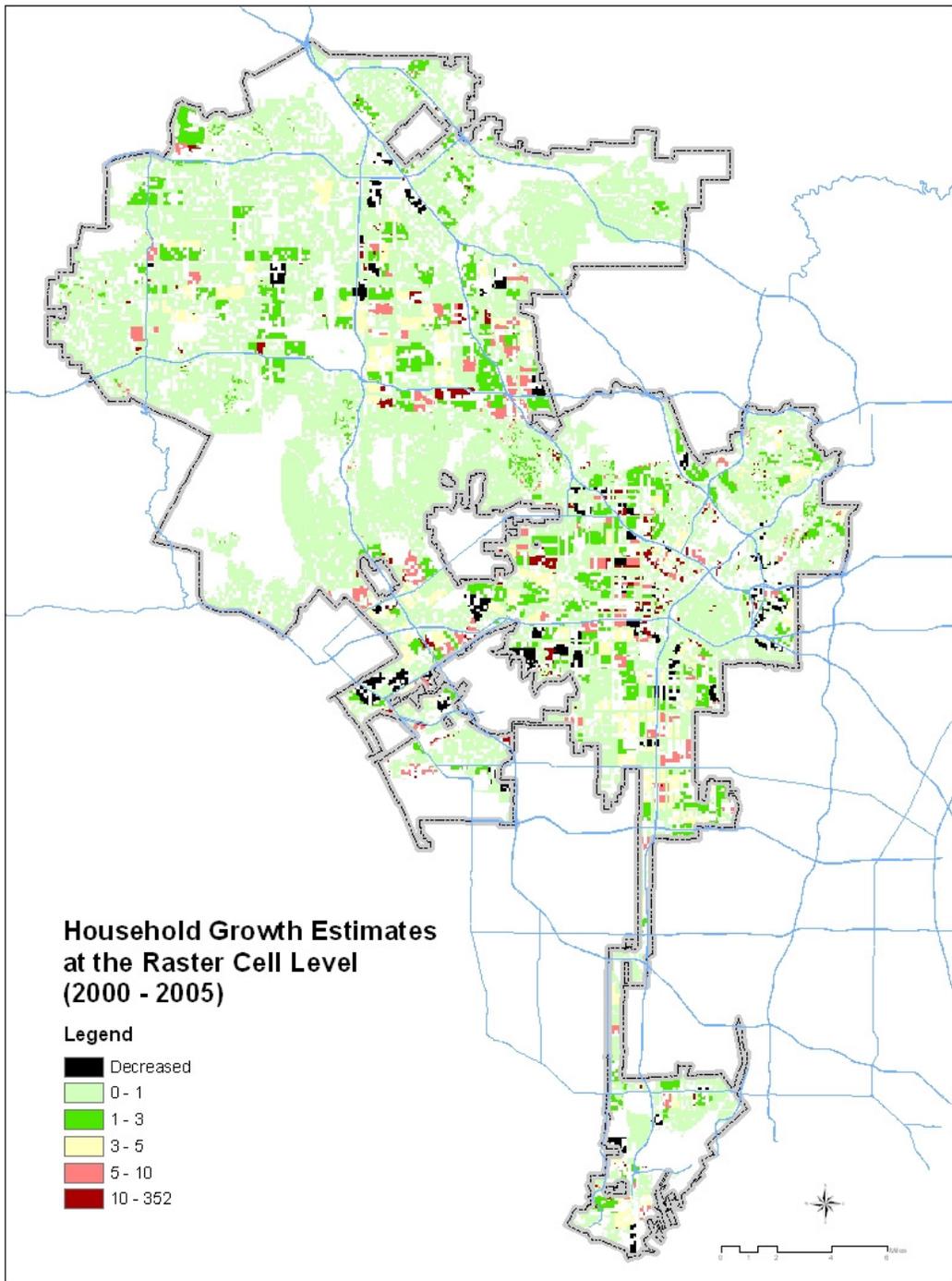


Figure 1. Household Growth Estimates at the Raster Cell Level, 4/1/2000-1/1/2006

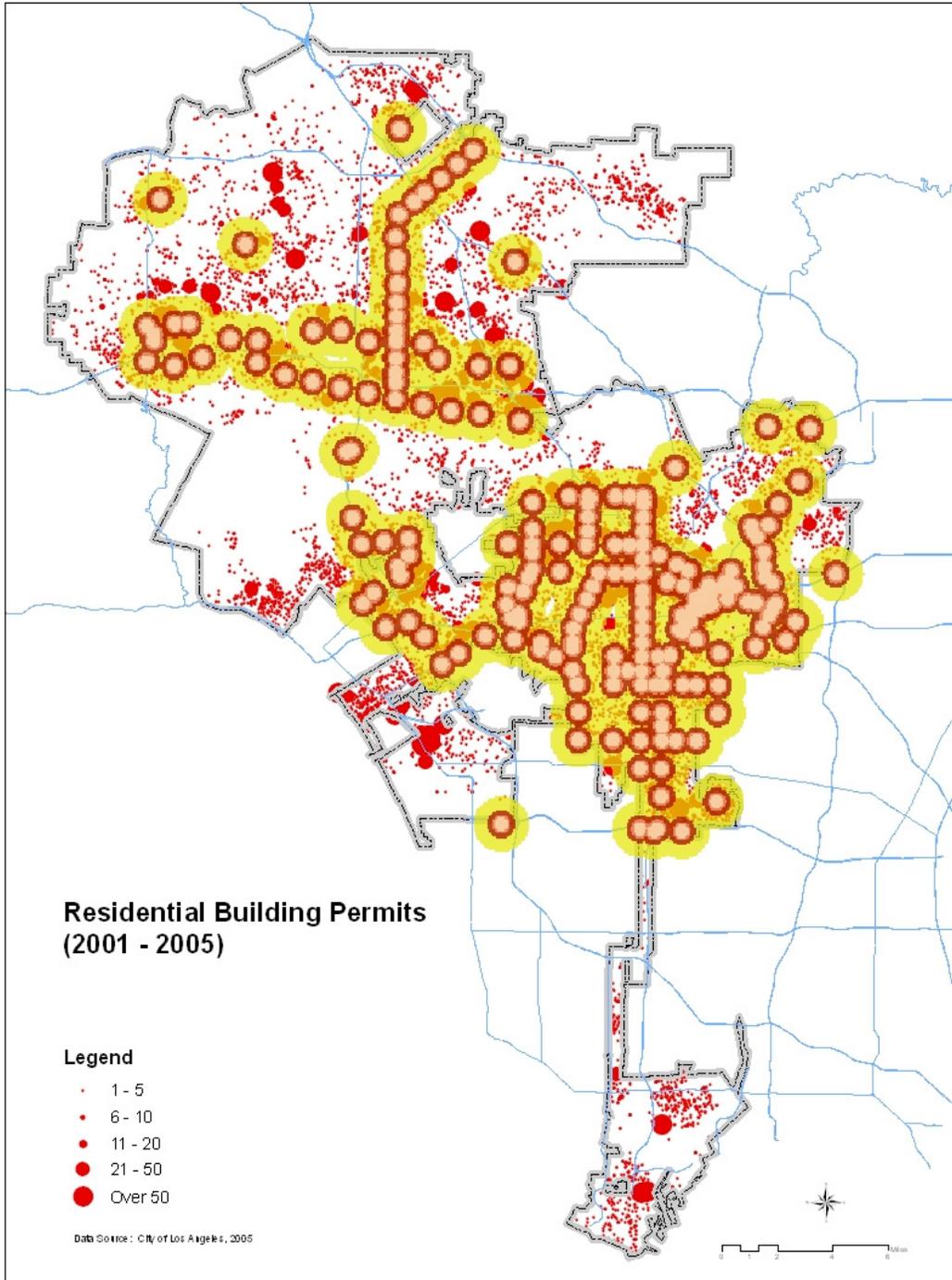


Figure 2. Transit Stations and Residential Building Permits, 1/1/2001-12/31/2005

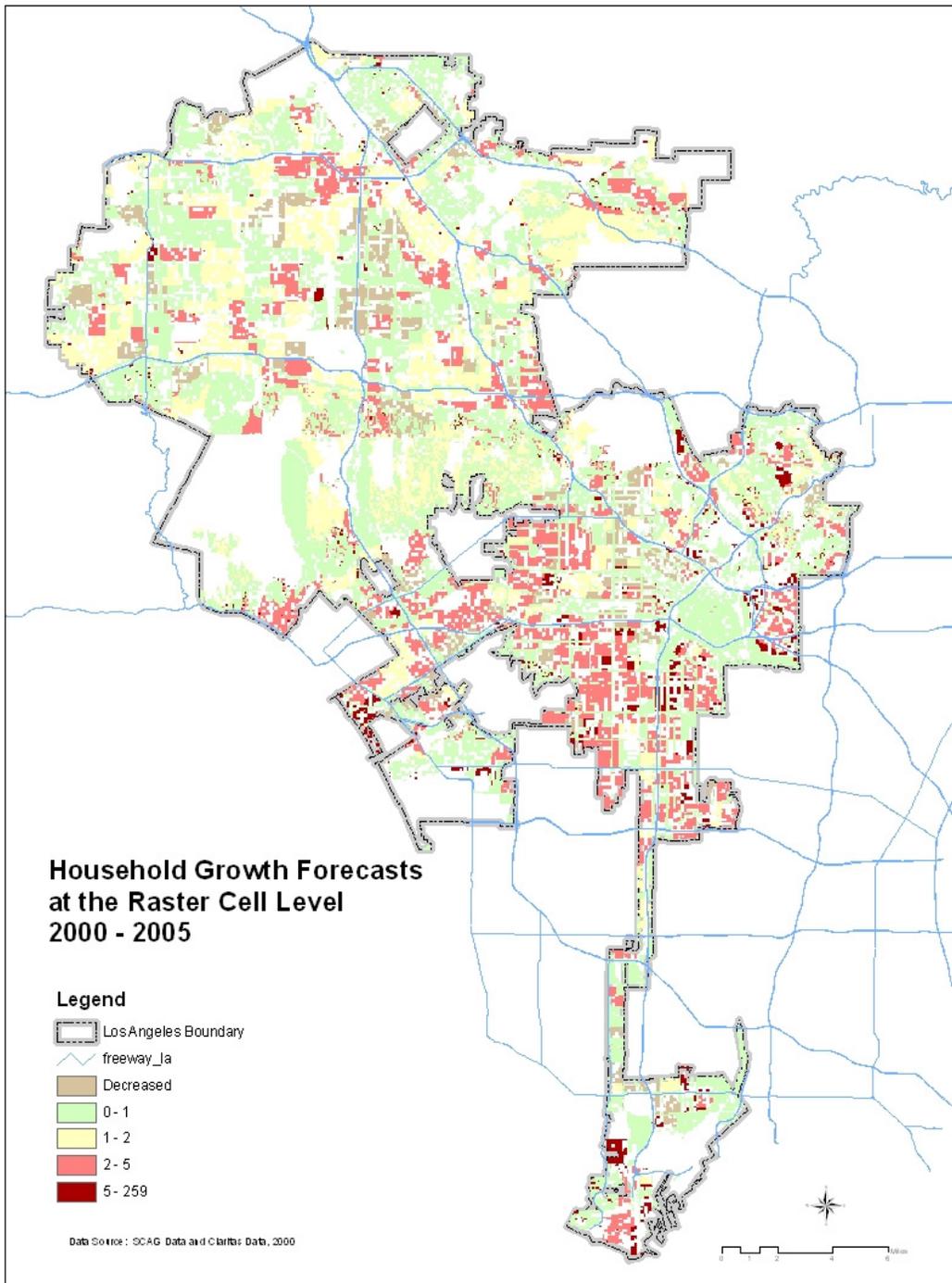


Figure 3. Household Growth Forecasts at the Raster Cell Level, 2000-2005

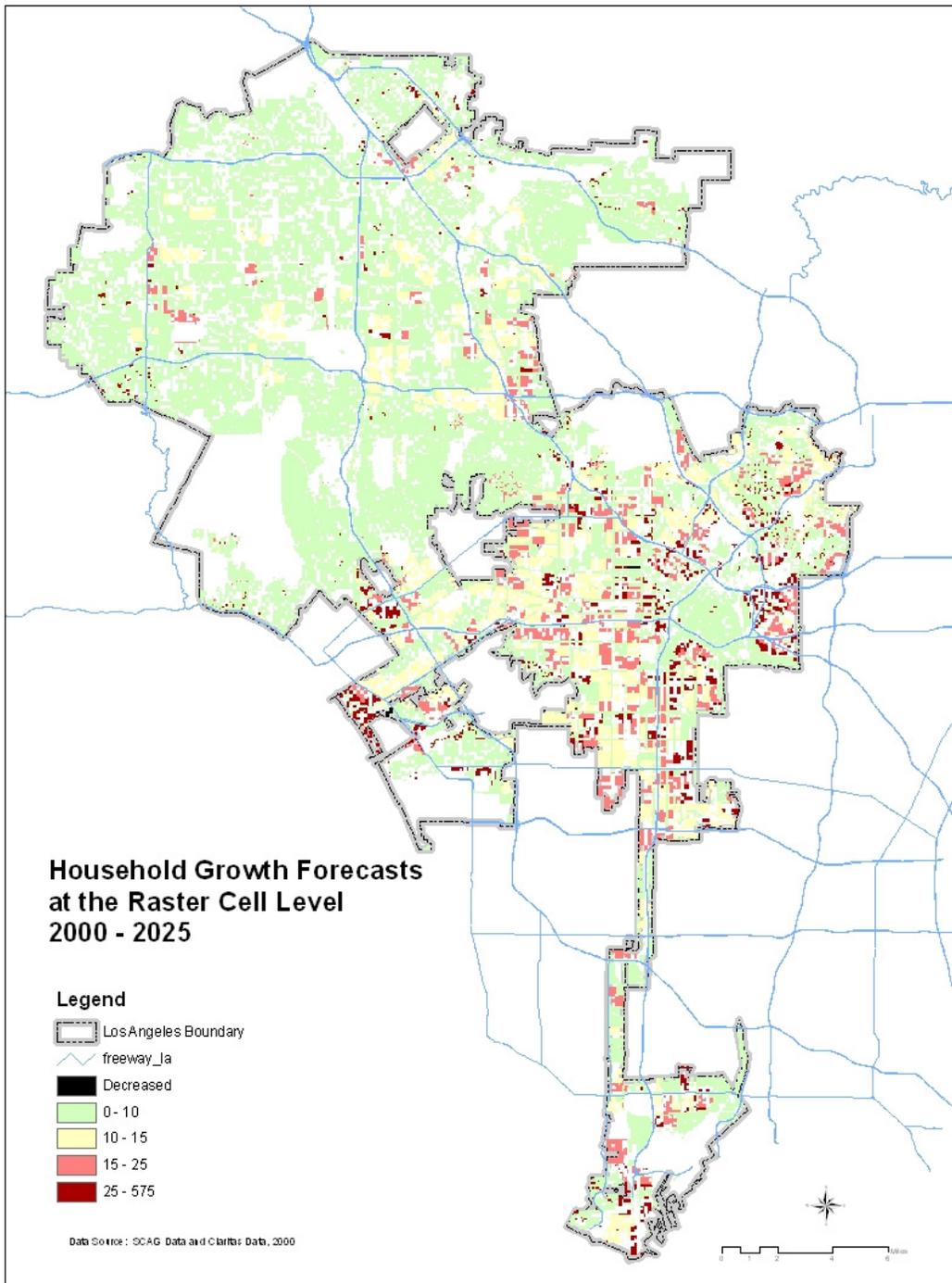


Figure 4. Household Growth Forecasts at the Raster Cell Level, 2000-2025

V. Conclusion

This paper presented a technique of monitoring small area growth with GIS. Monitoring growth of small areas becomes an important tool in measuring the progress of small area plans, such monitoring growth in and around transit oriented development areas. This study used the land use weighted interpolation to develop uneven and more accurate distribution of the socioeconomic estimates within the census tract of the City of Los Angeles. The raster cell level socioeconomic data estimates and forecasts were processed using land use information from both aerial photographs and local general plans. The study also showed how socioeconomic data at the raster cell level would be used to monitor the changing size and spatial distribution of small area housing growth, in particular, around the transit oriented development (TOD) area, to be able to provide additional information to policy-makers about current and future changes that may result in the placement of policies and investments.

Korea National Statistical Office(NSO) collects a variety of socioeconomic data through Korea Population and Housing Census. The smallest statistical area is Eup, Myon, or Dong. A few Dongs now reach the population size of 40,000. These areas' population is too large to represent the homogeneous characteristics of the area. Since 2000 Population and Housing Census in Korea, Korea NSO has shown an interest in developing the smaller statistical area for the public release. There has been a recent effort to discuss criteria to define the smaller statistical area(Seoul Development

Institute, 2007). With availability of socioeconomic estimates and forecasts at the smaller statistical area, the raster cell approach will be useful in analyzing and evaluating the small area planning and policy. Further research is needed to enhance the planning and policy applicability of the raster cell approach.

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- 원 고 접 수 일 : 2008년 7월 21일
1차심사완료일 : 2008년 12월 3일
최종원고채택일 : 2008년 12월 19일