7-1998

A GIS Methodology for Assessing the Growth Impacts of Highway Improvements

Thomas W. Sanchez
Portland State University

Kenneth Dueker
Portland State University

A GIS Methodology for Assessing the Growth Impacts of Highway Improvements

by

Thomas W. Sanchez, Assistant Professor
Center for Urban Studies
School of Urban Studies and Planning
Portland State University
PO Box 751-CUS
Portland, OR 97207-0751

Phone: 503-725-8743
Fax: 503-725-8480
E-mail: sanchezt@pdx.edu

and

Kenneth J. Dueker, Professor
Center for Urban Studies
School of Urban Studies and Planning
Portland State University
PO Box 751-CUS
Portland, OR 97207-0751

Phone: 503-725-4042
Fax: 503-725-8480
E-mail: duekerk@pdx.edu

Acknowledgements

The Oregon Department of Transportation provided support for this research.

A GIS Methodology for Assessing the Growth Impacts of Highway Improvements

ABSTRACT

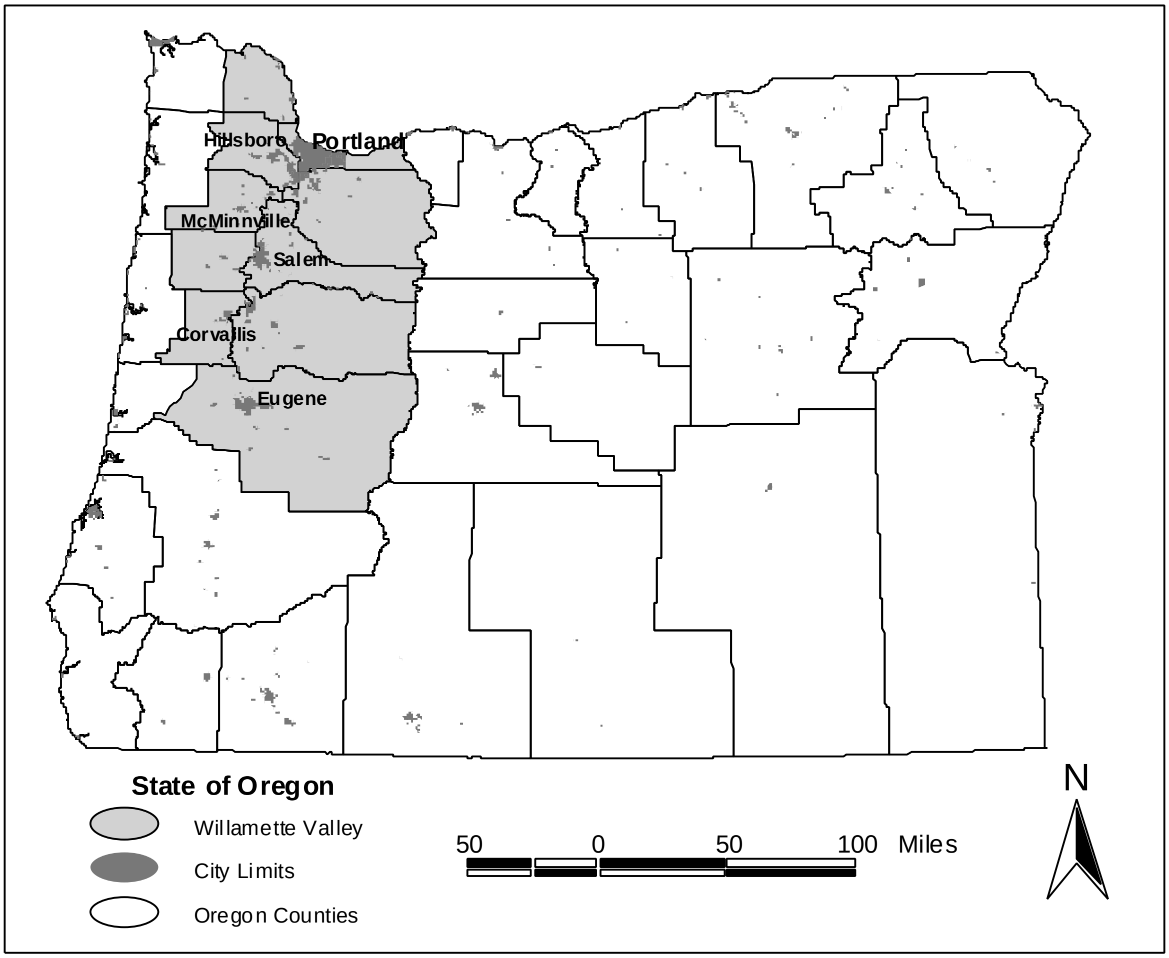
This paper presents a methodology to assess the induced land use effects of state highway improvements on urban development patterns. The methodology is applied to the case study City of Hillsboro, Oregon and illustrates a framework for data management and analysis. A set of temporal land use characteristics and spatial measures are used as predictors of urban development activities resulting from highway accessibility improvements. A multiple regression analysis tests the significance of these variables in predicting rates and locations of urban development. The primary objective of this research is to identify the relationship between capacity increasing highway improvements and changes in urban development. The analysis provides quantifiable indicators that describe the urban development trends associated with the City of Hillsboro.

INTRODUCTION

Much like many other states, Oregon has experienced significant rates of growth in and around its urbanized areas. The growth has not been limited to metropolitan areas with many non-metropolitan cities in the Willamette Valley also experiencing population increases in the range of 5 to 9 percent annually between 1970 and 1997 (U.S. Census 1998).

As urban areas increase in size, road and highway construction projects facilitate both work and non-work related travel demand. In the period from 1975 to 1995, per capita vehicle miles traveled (VMT) increased by more than 50 percent within the Willamette Valley (Gregor 1998). Much of this increase has been attributed to the large number of single occupancy commuters. The challenge is to accommodate local and regional travel demand with highway projects at the same time not encouraging dispersed development – especially at the urban fringe. This requires an understanding of the dynamic relationship between transportation and land use where accessibility increases from new highway facilities induce urban development and new development generates demand for new transportation facilities (Moore and Thorsnes 1994).

Figure 1 State of Oregon



Highway Improvements and Land Use

The underlying purpose for transportation investments is to improve accessibility. Accessibility refers to the ease of movement or interaction between geographic locations (Hanson 1995). There is always a cost associated with movement, typically measured in travel time and operating costs. The potential for interaction between places is increased as the cost associated with movement between them decreases. Accessibility is an inverse function of the physical separation between places, improved by the capacity of links connecting places, and the attractiveness of each place as a trip origin or destination. The role of urban transportation investments is to decrease the cost of movement between essential locations such as labor and industrial areas, and consumers and markets. Governments seek to promote economic efficiency in making investment decisions.

Transportation improvements that increase the accessibility of land and economic activities tend to have system-wide impacts rather than isolated impacts proximate to the specific improvements. It can be argued that patterns of urban land use are a consequence of the transportation network that links activities together. Thus, a change in the network can result in a redistribution of land use (De La Barra 1989). For example, a transport improvement that relieves or reduces congestion in a particular area can increase the attractiveness of that area for interaction and intensify activity. Land uses are continually seeking competitive cost advantages in terms of transport costs that change constantly due to associated changes in travel costs and benefits.

Location theories based on the interaction between transportation and land use have developed from distinct perspectives on residential, employment, retail, service, and industrial location (Wingo 1961, Giuliano 1989). There is not always an obvious link between each of these locational activities in theories put forth by researchers. However, it is accepted that each of these land uses locates relative to the other. This relationship may not be expressed explicitly by each theory, although the inclusion of land market characteristics may indirectly account for these interactions. Utility maximization at the firm or household level is also a common element among these theories.

In the case of urban transportation network improvements, productivity increases may produce changes in population and employment densities through impacts on capital-land ratios, development activities, and overall changes in the urban land market. In the case of transportation investments these changes are a function of the distribution of benefits (productivity gains) to landowners within an urban economy (Garrison 1979, Lee and Averous 1973). Because transportation facilities do not generate geographically uniform levels of service, variable spatial patterns of impact result.

Highway facilities have a significant impact on the number and desirability of sites for development. A new highway extending across urban boundaries creates a new set of travel and commuting patterns, which serve to increase the independence of the suburbs from the city. At the same time, intersections with highways create new foci for industrial, residential, and commercial development (Giuliano 1995). Interchanges afford particularly attractive nuclei for development of commerce and industry because they can serve areas for a considerable distance along highways as well as on intersecting highways. With two or more intersecting highways, these locations become even more enticing. In many cases, these accessibility increases have both local and regional land use impacts, so increased levels of urban development are not limited to properties proximate to the highway improvement.

METHODOLOGY

This investigation tracks development trends over a 20-year period for a selected Oregon city. A set of land use and other spatial measures are used as predictors of urban development activities resulting from highway accessibility improvements. The highway projects considered for this analysis are those directly related to capacity increases in and around the City of Hillsboro. Capacity increases include new highway extensions, lane additions, interchanges, and ramps. Changes to roadway configuration for access management (medians, turn lanes, driveway spacing, etc.) while potentially leading to increases in capacity are not considered. Local street and county road improvements, while important to local circulation, are not considered as capacity increases leading to significant urban growth. A multiple regression analysis tests the significance of the spatial measures in predicting rates and locations of urban development. A primary objective of this research is to identify the relationship between capacity increasing highway improvements and changes in land use intensity. The analysis provides quantifiable indicators that describe the trends in development activities.

Urban Change Detection Process

The following outlines the process used to convert aerial photography to the extent of urban development limits for the case study area of Hillsboro, Oregon. Aerial photos obtained from the U.S. Department of Agriculture, Farm Service Agency, Aerial Photography Field Office (USDA-FSA-APFO) for 1970 and 1990 were used to estimate the extent of urban development over time. The photography provided the physical coverage for Hillsboro and surrounding areas and ranged in fractional scale from 1:20,000 for the 1970 time period to 1:40,000 for 1990. All aerial photography was obtained as printed images that were then converted into a digital format so that they could be analyzed within a GIS. Because the photos generally do not cover entire urban areas, the set of photos had to be assembled to provide a complete geographic view of the study area. The resulting images were then registered to an existing layer of geo-referenced highway features from the United States Geological Survey (USGS). Each step is illustrated with a simplified example of the process used to estimate the change in urban development over time.

Figure 2 Step 1

Scan aerial photographs to obtain digital graphic image of study area

Figure 3 Step 2

Mosaic scanned photos together and crop to desired map extents

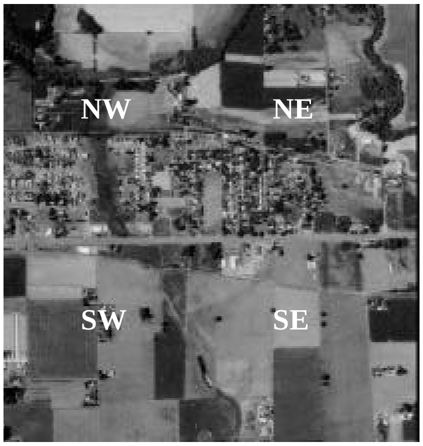
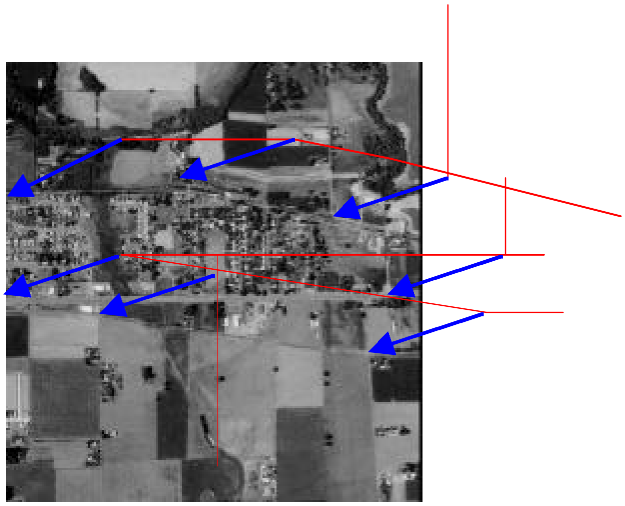


Figure 4 Step 3

Register and rectify the image to an existing geo-referenced coverage



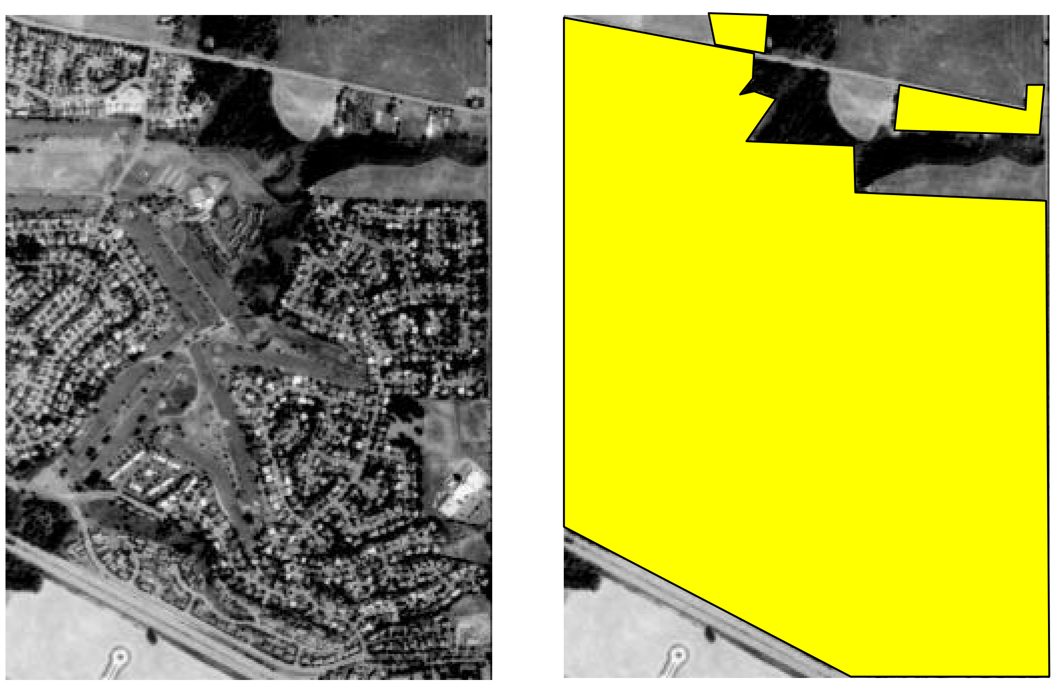
Before Registration

After Registration

Figure 5 Step 4

Digitize the boundaries of urbanized (developed) areas from aerial photos

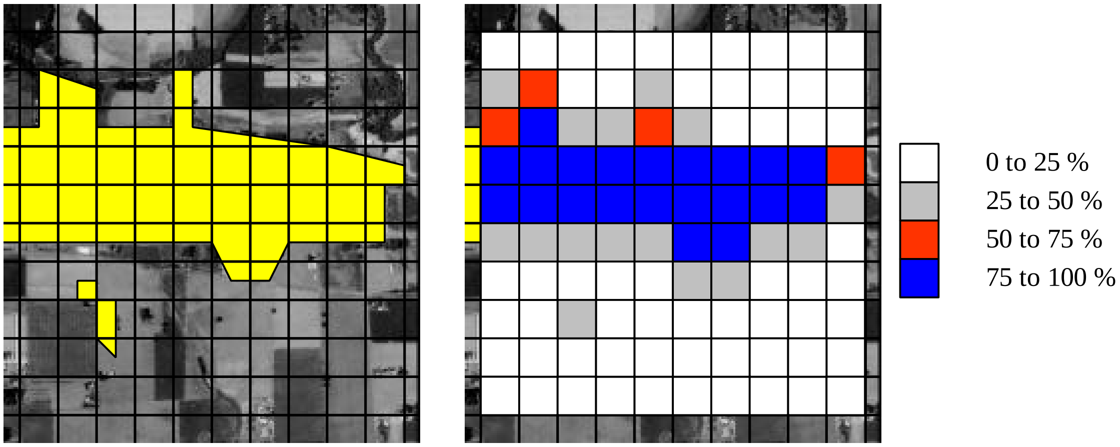
1970



1990

Figure 6 Step 5

Overlay a grid coverage on top of the digitized coverage of developed areas and calculate the percent of area within each grid cell that is developed



Urbanized areas were delineated using a manual method of digitizing. Areas were classified as being *urban* if development (residential, commercial, or industrial structures) was discernable from the aerial photography. Other unvegetated areas that had no structures but were contiguous to developed areas, such as parking lots or active open spaces, were also classified as urban. Areas located toward the center of the city that had dense vegetation with no visible structures or impervious surfaces were more likely to be considered urban because of their proximity to other urban land uses than were similar areas at the urban fringe. For example, recreational open space within cities would generally be considered urban, while farmland at the urban fringe would not (although farm houses and out buildings would generally be considered urban). In addition, areas considered to be at the *urban fringe* are those at the boundary of continuous urban development. The urban fringe does not typically coincide with city incorporated limits or urban growth boundaries (UGBs). Because this analysis is concerned with conversion of land to urban uses, the physical characteristics dictate how areas are classified rather than legal or administrative designations.

Hillsboro Analysis

Hillsboro, Oregon is a suburban community in the Portland metropolitan area and has experienced extensive population growth and urban development between 1970 and 1997. The population grew from 14,682 to 58,365 persons during this period (an average annual growth rate of 5.2 percent). As might be expected, development has tended to occur outward to the incorporated limits with some infill also occurring. From 1970 to 1990 the Hillsboro city limits expanded by 7,246 acres to accommodate this growth. Most of the undeveloped land within the current city limits is located to the northeast of the city. It is likely that development pressures will be exerted by the encroaching development from the neighboring city of Beaverton which is located to the east of Hillsboro. Figures 6 and 7 show the estimated change in urbanized area for Hillsboro between 1970 and 1990.

Figure 7 Urban development (1970-1990)

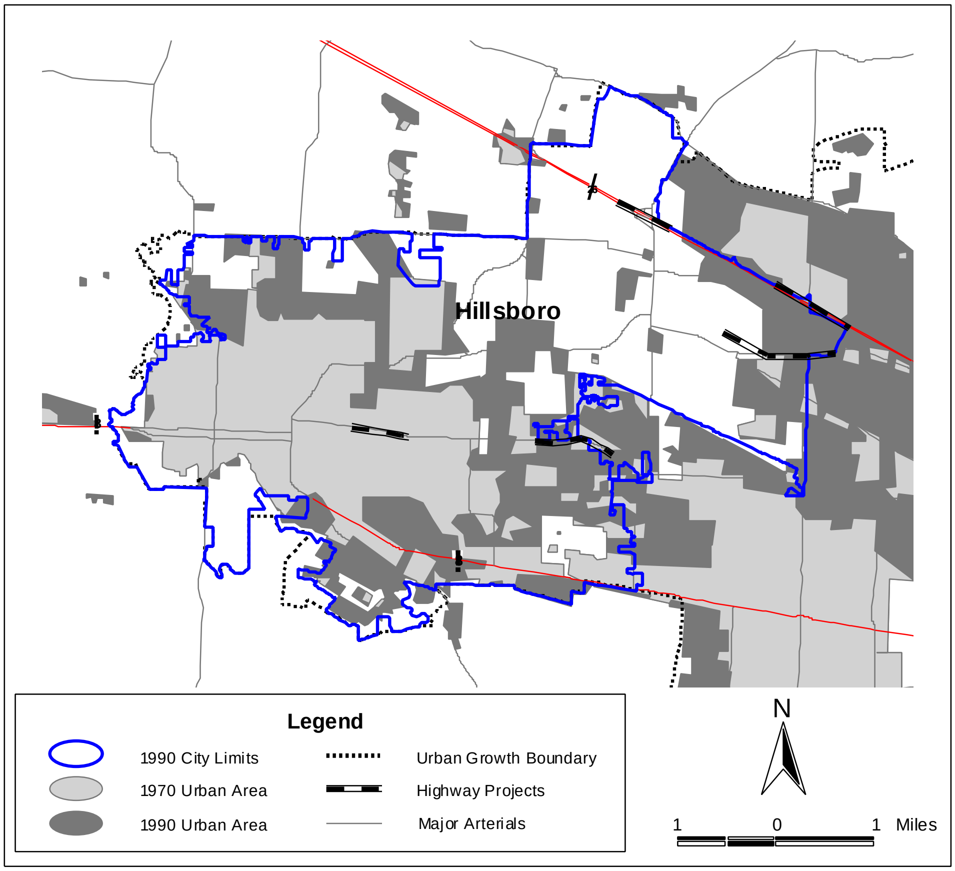
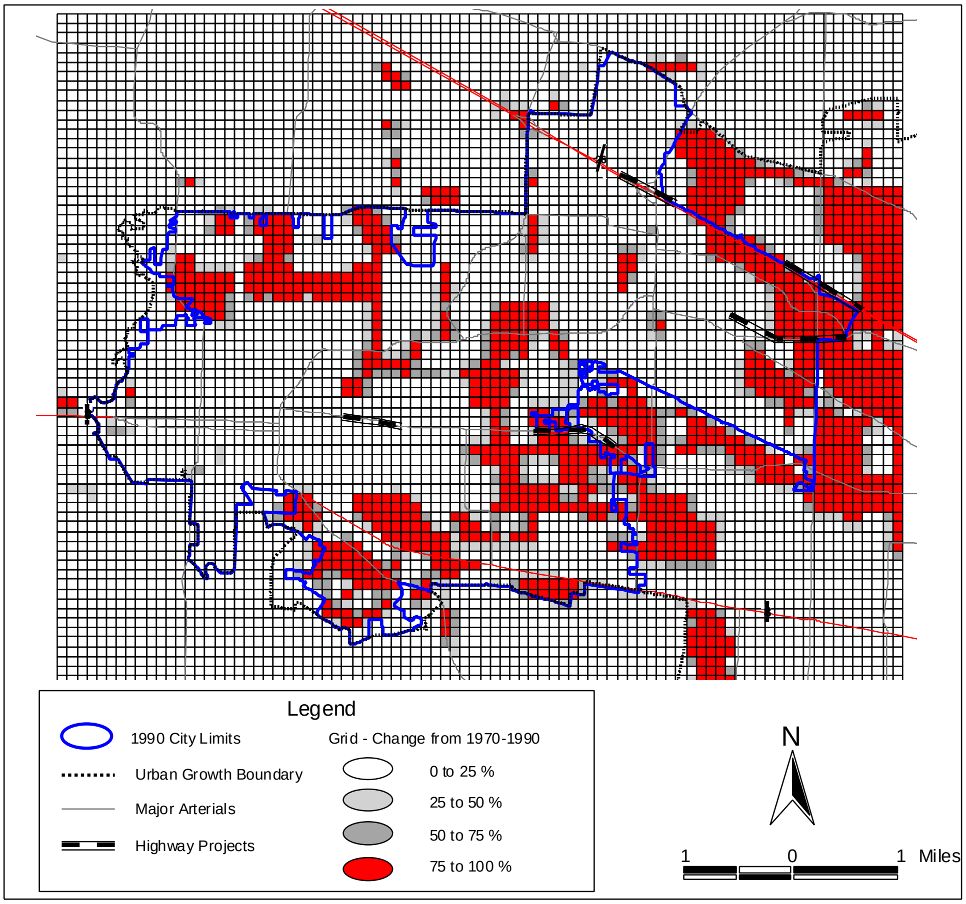


Figure 8 Change in urban status (1970-1990)



The analysis of aerial photography estimated that approximately 4,554 acres of land within the 1990 city limits were urbanized in 1970. The amount of urbanized land increased to an estimated 8,327 acres by 1990. This represents an 83 percent increase in developed land for the 20-year period and equates to the development of approximately 188 acres per year. During this period the ratio of persons per developed acre increased from 3.22 persons per acre in 1970 to 7.01 persons per acre in 1990. In addition to the amount of land being converted to urban uses, this analysis is particularly concerned with whether conversions are spatially correlated to the location of capacity increasing highway improvements. This analysis isolates the correlation between the location of urban land conversion and the location of highway improvements because the relationship between land use impacts and transportation facilities is typically seen as a function of physical proximity. The analysis controls for other spatial measures that indicate the likelihood of development. These measures are summarized in the Table 1. To account for nonlinear distance relationships, squared distances are included for each of the primary spatial measures. For example, along with the variable D_HIGHWAY (linear distance to the nearest highway) is D_H2, which is the linear distance to the nearest highway squared.

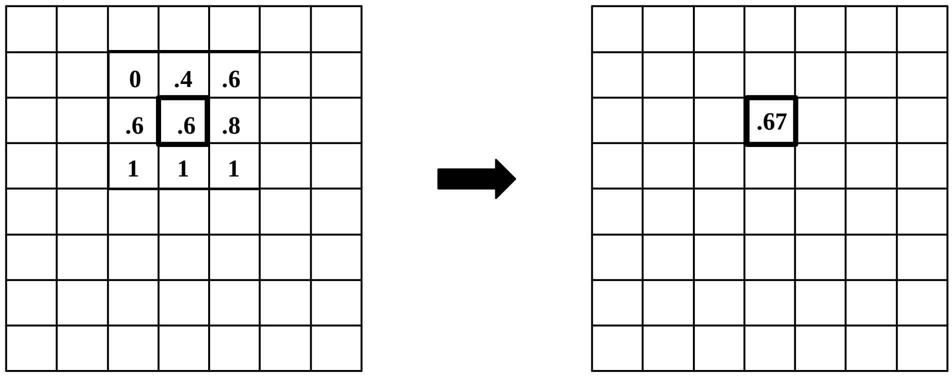
In addition to the spatial measures, the predominant land use zoning classification was assigned to each grid cell. The general zoning classes include commercial, industrial, rural, and single family residential. The multifamily zoning class is the omitted variable in the specification. The rural classification includes environmental resource lands, and land held exclusively for agricultural purposes.

Table 1 Variable descriptions

Measure	Variable
Linear distance to nearest highway (miles)	D_HIGHWAY, D_H2
Linear distance to UGB (miles)	D_UGB, D_U2
Linear distance to city center (miles)	D_CENTER, D_C2
Linear distance to nearest highway project (miles)	D_PROJECT, D_P2
Within 1990 city limits (0, 1)	IN_CITY
Neighborhood urban index (average percent)	NEIGH70
Number of years since project completion (years)	YEARS
Zoned as commercial (0, 1)	Z_COM
Zoned as industrial (0, 1)	Z_IND
Zoned as rural/agricultural (0, 1)	Z_RUR
Zoned as single-family residential (0, 1)	Z_SFR
Zoned as multi-family residential (0, 1)	Z_MF (Omitted)

All of the distance measures above are calculated as the straight-line distance from the grid cell centroid to the associated location (nearest highway, UGB, city limit, etc.) The *within city limits* variable is binary (0, 1), where 1 = within city limits and 0 = not within city limits. The zoning variables are also binary. The *neighborhood urban index* is the average percent urbanized of surrounding grid cells in 1970. This value was calculated for each cell using a neighborhood function within the GIS. Figure 8 shows an example of how cell values were calculated.

Figure 9 Neighborhood function on an individual cell



Input values (percent urban 1970)   Output values (average percent)

Regression Analysis

Regression equations incorporating the land use characteristics and spatial measures shown in Table 1 test the significance of proximity to highway projects as a factor in the rate of land use conversions. If the nearness to a highway project significantly affects accessibility and increases development potential close to the improvement, the regression coefficients for D_PROJECT should be negative. This means that as the distance to a highway project increases, the likelihood of being urbanized over time should decrease. The unit of analysis is the overlay grid cell (approximately 5.75 acres – 500 feet on a side). The first dependent variable is the percentage of the grid cell classified as urban in 1990 with grid cell values ranging from 0.0 to 1.0 (1.0 = 100 percent). The second dependent variable is the percent of land in the grid cell that converted to urban uses between 1970 and 1990. The change in urban area was calculated as follows:

$$CHANGE = (URBAN90 - URBAN70) / (1 - URBAN70)$$

If grid cell was completely urban in 1970, the observation was not included in the regression equation. If the grid cell percentage urban changed between 1970 and 1990, then the cell was assigned a value representing the proportion of undeveloped land in 1970 that was developed by 1990. This variable indicates the percent of land that was urbanized between 1970 and 1990 out of the total available in 1970. Grid cell values range from 0.0 to 1.0 (1.0 = 100 percent). Tables 2 and 3 shows the regression results for Hillsboro.

When many spatial measures are included within a single specification there is an increasing concern about multicollinearity. Undetected multicollinearity can bias regression results and potentially lead to unreliable regression coefficients (Neter, Wasserman, and Kutner 1989). For this analysis it is possible that there may be a high degree of correlation between the *distance to nearest highway* and *distance to nearest highway project*. In addition, it is possible that the measures of urban proximity; *within city limits*, *distance to UGB*, and *distance to city center* are correlated. If a city boundary was a perfect circle, then the distance to the center (inside) would have a significant negative correlation with the distance to the boundary (outer edge). Testing variance inflation factors proved to be problematic due to the inclusion of the squared terms of the spatial indicators. As an alternative test, 11 iterations of regression were run removing individual variables in succession. For example, first D_CENTER and D_C2 were excluded from the regression equation. D_CENTER and D_C2 were returned and D_HIGHWAY and D_H2 were excluded, and so forth. In virtually all cases the sign of the coefficients remained constant, except for D_U2 and YEARS, which were the only 2 statistically insignificant variables in the full specification. The r-square values of the regressions were consistently in the range of 0.61 to 0.62, except in the case of the NEIGH70 variable where the r-square value dropped to 0.56. Based on the results of this test, multicollinearity does not appear to be having a substantial influence on the regression model.

Table 2 Regression results for dependent variable URBAN90 (percent urban in 1990)

Multiple R	.79441
R Square	.63108
Adjusted R Square	.62979
Standard Error	.27792

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	15	563.41605	37.56107
Residual	4264	329.35983	.07724

F = 486.27789 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
D_CENTER	-.374486	.025296	-.791896	-14.804	.0000
D_C2	.067234	.004200	.792765	16.009	.0000
D_HIGHWA	-.288334	.028806	-.379749	-10.009	.0000
D_H2	.100857	.012501	.296196	8.068	.0000
D_PROJEC	.189220	.027952	.262557	6.769	.0000
D_P2	-.107233	.015297	-.263025	-7.010	.0000
D_UGB	.074725	.026579	.098801	2.811	.0050
D_U2	.011602	.012696	.032143	.914	.3609
IN_CITY	-.123246	.014223	-.134001	-8.665	.0000
NEIGH70	.800936	.027947	.312693	28.659	.0000
YEARS	-4.04007E-06	.002466	-2.673E-05	-.002	.9987
Z_COM	.103853	.026974	.049228	3.850	.0001
Z_IND	-.185630	.021687	-.166566	-8.559	.0000
Z_RUR	-.349124	.024038	-.372097	-14.524	.0000
Z_SFR	.143095	.020598	.143353	6.947	.0000
(Constant)	.985496	.054015		18.245	.0000

Table 3 Regression results for dependent variable CHANGE (percent change from 1970 to 1990)

Multiple R	.75822
R Square	.57489
Adjusted R Square	.57340
Standard Error	.29754

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	15	510.49766	34.03318
Residual	4264	377.49136	.08853

F = 384.42594 Signif F = .0000

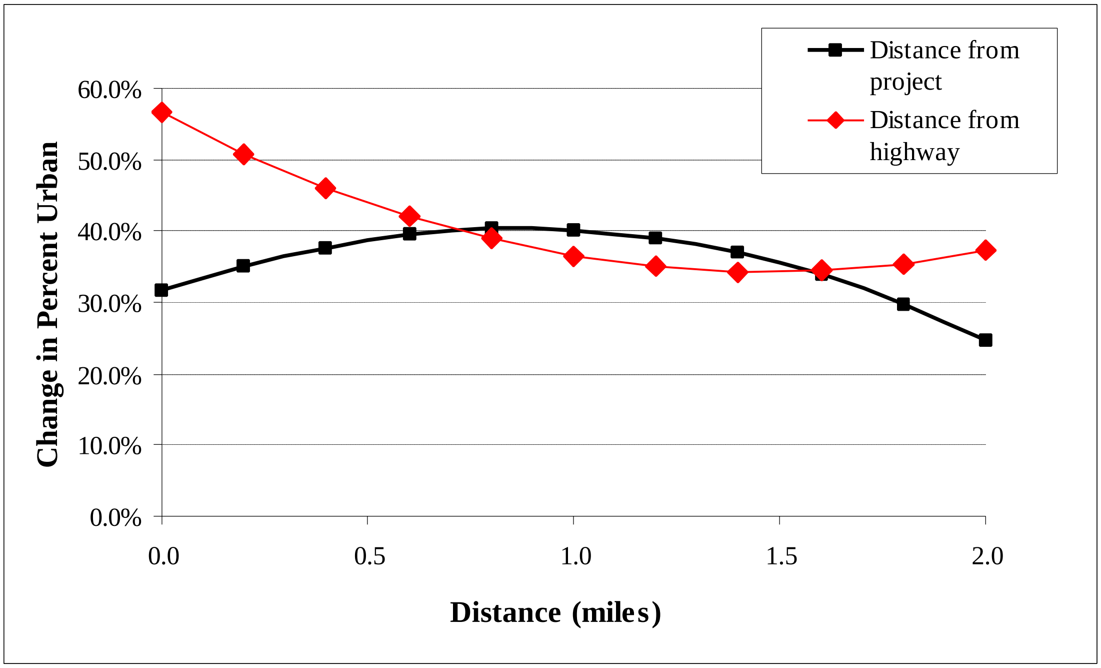
------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
D_CENTER	-.423353	.027081	-.897642	-15.633	.0000
D_C2	.073935	.004496	.874123	16.444	.0000
D_HIGHWA	-.303837	.030840	-.401243	-9.852	.0000
D_H2	.103671	.013383	.305278	7.746	.0000
D_PROJEC	.212824	.029925	.296103	7.112	.0000
D_P2	-.122535	.016377	-.301367	-7.482	.0000
D_UGB	.119650	.028455	.158627	4.205	.0000
D_U2	-.004937	.013593	-.013713	-.363	.7165
IN_CITY	-.149451	.015226	-.162930	-9.815	.0000
NEIGH70	.578569	.029920	.226487	19.337	.0000
YEARS	-.002783	.002640	-.018461	-1.054	.2920
Z_COM	.103370	.028877	.049131	3.580	.0003
Z_IND	-.170738	.023218	-.153615	-7.354	.0000
Z_RUR	-.348747	.025735	-.372695	-13.551	.0000
Z_SFR	.164856	.022051	.165597	7.476	.0000
(Constant)	1.072222	.057827		18.542	.0000

The model performs relatively well in predicting the degree of "urban-ness" for 1990 as well as the degree of change during the 20-year time period. The regression explains approximately 63 and 57 percent of the variation among grid cells values respectively. The coefficients for the *squared distance to the UGB* (D_U2) and the *years since the highway project completion* (YEARS) were the only coefficients that were not statistically significant at $p < 0.01$. The negative coefficient for *distance to nearest highway* reflects the importance of proximity to transportation, and the positive sign for *distance squared* is the expected diminishing effect of distance. The opposite signs for corresponding coefficients *for distance to nearest highway project* appear at first impression to be counterintuitive, negating the effect of nearness to transportation investment. Apparently the new highways affect accessibility of the system and felt more significantly in the vicinity. The *distance to the nearest highway project* coefficients (D_PROJECT and D_P2) can be interpreted as meaning that holding all other factors constant, development activity peaks approximately 0.9 miles from the nearest highway project and then declines gradually beyond that distance. It appears that state highway projects are providing accessibility through the highway as a system that enables urbanization and is less important than distance to the nearest highway facility. Given the other locational factors being controlled, this appears to be a significant and logical relationship. Figure 10 graphically depicts the non-linear relationship between distance and the degree of development occurring at a particular location.

The urban status of surrounding properties (the NEIGH70 variable) and the zoning classification have a significant impact on whether a particular location was developed for urban purposes. The *neighborhood* variable controls for the natural "spread effect" of urban development pressure. The coefficient for this variable is positive and significant for predicting the urban development pattern in 1990. This suggests that land is more likely to be developed if surrounding properties are developed. The coefficient for this variable is also positive and significant for predicting the change in urban-ness from 1970 to 1990. The land use zoning variables were also useful in predicting trends in development patterns. Land zoned for single family residential and commercial land uses were more likely to be developed compared to land zoned as industrial or rural. This suggests that rural and agricultural designations have generally inhibited development while growth accommodating commercial and residential zones were associated with changes in urban land use intensities.

Figure 10 Change in urban development from 1970 and 1990 (using averages for other variable values)



Measurement Error

The manual method of digitizing urbanized areas from aerial photographs involves a degree of error in a few different forms. Image distortion, edgematching errors, and image registration errors potentially contribute to either over- or under-estimation of the total urbanized areas. Because the analysis is performed at a relatively small geographic scale and because the general rates of development are being reported, it is likely that the overall level of error in estimates of urbanized areas do not significantly affect the outcomes of the analysis.

Additional measurement errors may also result from the methods used to estimate accessibility measures. In this case the straight-line (Euclidean) distances from grid cell centroids to the nearest highway, highway project, and city center were used rather than the road network distance or travel time. In addition, the distances to the nearest highway and highway project were measured from the grid cell centroid to the nearest point along each line segment, rather than to the actual access point such as on-ramp or interchange. It is probable that these measures do not have an adverse affect because of the geographic scale of the analysis. More detailed network analysis would probably not add much variation to the relative accessibility measures for each of the grid cells.

CONCLUSIONS

The analytical method described in this paper incorporates a set of commonly used data sources and techniques to assess highway capacity increase impacts on urban development patterns. The statistical analysis for Hillsboro, Oregon, suggests that selected spatial measures perform adequately in predicting urban growth trends from 1970 to 1990. Land use zoning regulations also proved to be significantly correlated with the location and extent of development.

Of most significance to this analysis, the results of the regression model indicate that urban development in Hillsboro is less driven by close proximity to state highway projects as it is to the nearest highway facilities as depicted by the gradients in Figure 10. It should be noted that the analysis did not account for intra-urban transportation network improvements administered by the City of Hillsboro or Washington County. Non-highway improvements may certainly improve circulation and congestion conditions, but not have the growth inducing impacts that major highway capacity increases tend to produce. In the case of Hillsboro it appears that highway capacity increasing projects, which are typically a response to current or anticipated increases in travel demand, have not lead to direct and immediate land development activities.

The current analysis could be greatly enhanced if the change in type and density of development were examined over time. The analysis of the aerial photography could not account for the characteristics of development, instead, only the occurrence of urbanization could be detected. Subsequent stages of the current research will be concerned with specific land use characteristics. The current research is being extended to 19 additional urban areas in Oregon to provide a more comprehensive analysis of growth trends and impacts. In addition, specific highway corridors will be part of detailed analyses of local area land use changes that result from highway improvements. The proposed methodology will be further refined as a result of the additional data collection and analysis.

REFERENCES

De La Barra, T. *Integrated Land Use and Transport Modelling*, Cambridge University Press, Cambridge, 1989.

Garrison, W.L. Urban Transportation and Land Use in G.E. Gray and L.A. Hoel, eds. *Public Transportation*, Prentice-Hall, New York, 1979.

Giuliano, G. Research Policy and Review 27: New Directions for Understanding Transportation and Land Use, *Environment and Planning A*, 21, 145-159, 1989.

Giuliano, G. Land Use Impacts of Transportation Investments: Highway and Transit. In S. Hansen, *The Geography of Urban Transportation*, The Guilford Press, New York, 1995.

Gregor, B. *Commuting in the Willamette Valley*. Report prepared for Federal Highway Administration and Oregon Department of Transportation, May 1998.

Hanson, S. *The Geography of Urban Transportation*, The Guilford Press, New York, 1995.

Lee, D.B. and C.P. Averous. Land Use and Transportation: Basic Theory, *Environment and Planning*, 5, 491-502, 1973.

Moore, T. and P. Thorsnes. *The Transportation/Land Use Connection*. Report Number 448/449, Planning Advisory Service, Chicago, 1994.

Neter, J., W. Wasserman, and M.H. Kutner. Applied Linear Regression Models. Irwin, Homewood, 1989.

Wingo, L. Jr. *Transportation and Urban Land*, Johns Hopkins Press, Baltimore, 1961.