LAND USE CHANGE AS A TOOL: A FRAMEWORK TO LINK TRANSPORTATION AND THE ENVIRONMENT IN NEW DELHI, INDIA.

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Total Words: 4965 (text) + 3750 (from figures) = 8715

Abstract

Cities in developing countries like India are facing some of the same concerns that North American cities are: congestion and urban growth. However, the concern in cities like New Delhi, India is that this growth is far more rapid as both urbanization and motorization are ongoing processes that have not yet peaked. Furthermore air quality in major Indian cities is now becoming a major concern with TSP (Total Suspended Particulates) levels at dangerously high levels. In this paper, we examine this land use change and its relationship with transportation and air quality in a spatial context to pinpoint locations for concern. Like many urban processes the spatial nature of these problems is self-evident. Air quality affects the various strata in the population differently depending on where they live and people live in different parts of the city depending on their socio-economic status. We estimate cellular automaton and discrete choice models of land use change. The former is used to look at various cities in India including Delhi, Mumbai, Chennai and Bangalore. The latter is used for New Delhi alone. The results suggest that land use in the New Delhi metropolitan area is rapidly intensifying and that planners and policy-makers need to address industrial, commercial and infrastructure location in order to plan for a more sustainable city. We also examine these results in the context of a framework that can be used to link land use, transportation and air quality models for cities like New Delhi.

INTRODUCTION

New Delhi is one of the ten most polluted cities in the world according to the World Health Organization (WHO) (*1*). The WHO notes that traffic congestion in the city is high and that average speeds vary from, about 15 km/hr on local streets in central areas, to about 40km/hr on arterial streets. The number of traffic related fatalities are also very high (*2*). Private car ownership is rising, though it is low compared to developed countries. The mix of vehicles on the roads is unique in that road space is shared by non-motorized as well as motorized vehicles. Gakenheimer (*3*) notes that mobility and accessibility are declining in most of the cities in the developing world. He suggests that these cities have a stronger land use transport relationship than in developed cities. When this is coupled with a lack of adequate road maintenance and limited agreement among the government agencies as to appropriate ways to tackle the problems of motorization and urbanization, congestion and consequently air quality continue to worsen.

Traditionally, transportation related air quality policies in developed countries like the US have emphasized cleaner vehicle and fuels technologies and alternatives to single occupant vehicle travel such as car-pooling and mass transit. Kessler and Schroeer (*4*) note that traditional highway projects are justified on the grounds that they will increase speeds and improve air quality. However, running emissions are declining as a portion of total mobile source emissions, minor improvements in vehicle speeds contribute little to the overall emissions picture. As India adopts the Euro III and IV guidelines vehicles will get cleaner. However, the sheer numbers of people and vehicles forecasted in the future for New Delhi and its environs indicate that congestion will continue to worsen even if new highways are built (and there appear to be no current plans for new roadways). Thus, congestion and air quality needs to be tackled through other alternative policies. Bartholomew (*5*) notes that the LUTRAQ (Making the Land use, Transportation, Air Quality Connection) study found a significant relationship between land use mixing and auto ownership and mode choice and that pedestrian friendly locations encouraged more walking. Delhi is already a mixed-use city and has relatively high fuel and travel cost prices. A large proportion of trips are walking or bicycle trips and 40% of the trips are less than 5km in length and 50% of all motorized trips are by public transport (*2*). However, accessibility is poorly distributed, as it is in most developing cities of the world (*6*). Matching land use development to feasible transportation capacity, jobs housing balance to put workers within range of jobs and efficient mixed uses are all possible strategies for land use and transportation planning that addresses the air quality problems of New Delhi. In this paper, we analyze the changes in land use between the years 1962-1999 and its relationship to transportation characteristics like the presence of highways and railroads in order to address the future location of population and employment in the New Delhi metropolitan area.

LAND USE CHANGE MODELS

Theories of land use

Von Thunen formulated the first empirical evaluation of land use activity in the early 19th century. His study linked the intensity of land use type of land use and land values to transportation modes. The two basic scenarios produced were:

- A series of annular rings with progressively less intense land use as distance increased from market centers
- The availability of water transportation created a corridor of intensive land use taking advantage of reduced transportation costs.

The sector model was formulated by Hoyt in 1938 and he recognized the concentrations of industrial land uses along water courses and railway lines. His model is often referred to as the radial corridor model. The final urban morphological model appeared in 1945 – Harris and Ullman's multiple nuclei model that referenced road transportation. Mayer (*7*) illustrated the impact of different time periods with their different transportation models on urban spatial structure. He suggested that throughout time large cities may incorporate structural attributes from all three of the above models. Warren (*8*) notes that there have been two basic models in the modern industrial metropolis with both being based on the provision of transportation facilities. They are:

- The transit corridor model
- The roadway centers model

The former is keyed into the provision of high capacity mass transit services, while the latter is prefaced to the development of a grid of freeways and arterial roadways. He notes that other secondary features such as the history of development, topography, riparian and water features will influence the morphology of a city's land use development. The minimum size for the transit corridor is determined by the size limit requirements for supporting mass transit. Until recently this limit was suggested to be 2 million, though cities such as Portland have successfully instituted light rail services with a population of 1 million. Clearly, at nearly 14 million people (2001 Indian Census) New Delhi exceeds this limit. Sarna et al (*9*) note that only Bombay (Mumbai) has been able to achieve a modal split of 85% in favor of mass transit and Calcutta (Kolkata) of 80% due to their linear form. Delhi (See Figure 1) has an urban form that appears to follow the radial corridor.

Other studies of land use change

Other studies of land use change in developing countries (*10; 11; 12*) emphasize land cover change rather than land use change and tend to study the rural/urban change rather than the intra-metropolitan level land use change. While this change is clearly very important to understanding environmental changes at the macro level, the planners in the New Delhi region need to understand changes at the regional and metropolitan level for effective provision of infrastructure. Fischer and Sun (*13*) point out that land-use changes are directly linked with economic decisions. Therefore they adopt an economic framework as the organizing principle for their models predicting regional land use in China. Walker (*14*) presents a model that takes "the urban model stemming from Alonso and weds it to the agricultural model developed by von Thunen" for the Florida Everglades. Others have used cellular automaton models to simulate socioeconomic effects on land use change (*15; 16*). A Markovian process is one in which the state of a system at a later time can be predicted by the state of the system at an earlier time. One of the basic spatial elements that underlie the dynamics of many change events is proximity. A cellular automaton is a cellular entity that independently varies its state based on its previous state and that of its immediate neighbors according to a specific rule. The assumptions underlying this method tend to be somewhat simplistic when looking at the micro-level changes in land use. Zhang and Landis (*17*) present a survey of recent studies that look at land use change. They use a discrete choice framework to study land use change by county in the San Francisco Bay Area between 1985-1990. Their research indicates that distance from the CBD, proximate uses, site topography, population growth are all important explanatory variables. Chomitz and Gray (*18*) also estimate the probabilities of alternative land uses as a function of land characteristics and distance to market in Belize using a discrete choice framework. In this paper we first examine land use change within the Cellular Automaton (CA) and Markov modeling framework for a few Indian cities and then look in particular at land use change in New Delhi with the help of discrete choice models. We also examine change with respect to intensification of land uses and loss of variety since both play a role in changing urban characteristics that impact the need to travel *(19*).

LAND USE CHANGE IN URBAN INDIA

Population data for 1962 and 1998 for the cities of New Delhi, Mumbai, Chennai and Bangalore (*ISCIENCES, 2000*) was used for forecasting urbanization in 2036 using a cellular automaton and Markov land use change model (*IDRISI, 2001*). Urbanization was modeled based on density, which was classified as:

1. rural (< 1000 persons per sq km)

2. suburban (1000-5000 persons per sq km)
3. urban (> 5000 persons per sq km)

Rural suitability was based on availability of moisture, average annual rainfall, access to streams, soil type/agricultural productive potential, slope and land cover suitability to agricultural use. Urban and suburban suitability was based on identification of macro-economic zones in close proximity to existing cities (larger cities have a higher "attraction" than smaller cities). These locations into two density types based on proximity to urban centers, water availability, slope, roadways and railways.

Suitability maps for each land use type are considered as an objective. For each host class, the suitability maps of all others are masked and then, for each mask image a contiguity filter is used to weight contiguous areas. The area requirements for each land use category are taken from the transitions areas file developed using a Markov model. Finally, an overlay is applied to all the results onto the base land cover map. The results predicted by this model are indicated in Figures 2, 3, 4 and 5 for the four cities. It is apparent from the maps that if current growth rates continue the predicted level of urbanization indicates "megacities" with very high densities.

Clearly, the CA/Markov based model is a simple simulation model. It does not use data on population, employment or other socioeconomic characteristics that may be relevant to land use change. Also, it may not be useful to those planning at the intra-metropolitan level where micro-level changes in land use may be more important. For this reason, we look at more detailed land use changes for New Delhi and examine these changes within a discrete choice framework.

LAND USE CHANGE IN NEW DELHI

Land use data for 1962, 1990 and 1999 for the metropolitan New Delhi area (538 sq. km) was obtained from a private company in New Delhi (*MLINFOMAP, 2001*) for this research. This data was interpreted from IRS data for those years and corrected by on-site checks. Clearly, residential densities have increased and open spaces have decreased over the years (Figures 6 and 7). However, the changes appear to be more rapid between 1990 and 1999 when compared to the changes over the previous thirty years. In order to analyze the determinants of these changes we model changes in intensity of land use over the two time periods and forecast the probability of change. In this paper we regard change "upwards" that is the order of change in intensity is as follows in order of increasing hierarchy:

1. Open space
2. Residential (with increasing densities)
3. Office/ Commercial
4. Industrial

Table 1 indicates that the changes between 1962-1990 in terms of intensification and variety were smaller than the changes in intensity between 1990-1999. In the period 1962-90 about 1/3rd of the sampled cells intensified, however in 1990-99 about half the cells intensified in terms of land use. Figure 8 indicates that there were also changes in variety. Most wards lost variety in terms of the number of land uses. This could be a function of the data quality but it indicates the beginning of a trend whereby the land uses are homogenizing. Also, between 1962 and 1990 1/4th of the cells lost variety, between 1990 and 1999, 90% of the cells lose variety in the 2km buffer surrounding the cell. In order to determine if these changes were related to transportation infrastructure, we estimate a discrete choice model, which is further elaborated in the next section.

Discrete choice model

Discrete choice models are applications of linear regression models where the dependent variable is of qualitative choice. The geo-unit's change over the two time periods 1962-90 and 1990-99 is estimated as a binary "choice". The geographical unit is a 0.5x0.5 km grid cell derived from a raster conversion of the metropolitan area's land use coverage. A random sample of 3209 grid cells was obtained from the 10,000 grid cells that define the city coverage to avoid spatial autocorrelation.

The dependent variables (0/1 discrete where 1 indicates change and 0 indicates none) were:

1. Intensity of land use:
   Went up if it went to higher use (from open to residential to office/commercial to industrial)
2. Variety of land use:
   Went down if the number of land use categories within 2 km of grid cell decreased from base year

Independent variables include:

1. Initial land use (open space, residential or industrial)
2. Distance (average) from
   highway,
   railway,
   central business district,
   district center
3. Percentage land devoted to commercial, open space, residential uses
4. Population density in base year (and employment density when available)

In the 1962-90 period distance from highway was significant in that, proximity to highways increased the likelihood of land use change. However, between 1990 and 1999 this coefficient was insignificant perhaps indicating that industries that depended on the highways had already consolidated close to highways in the previous time period. Road density was significant in both time periods but with opposite effects. Places with high road density tended to intensify in terms of land use in 1962-90 while they were less likely to intensify in 1990-99. In the latter time period, unlike the earlier time period, distance to railroads was significant. Thus, the closer the site was to railroads, the less likely it was to intensify in terms of land use. Perhaps, this is related to the lessening dependence of industries on railways for transporting goods.

The results of variety change models (Tables 4 and 5) confirm that a drop in land use variety during the two time periods were also very different. The former model has low ^{2} (0.23) but some significant coefficients. The later model has high ^{2} (0.72) and several significant coefficients. As in the intensity change models initial land use being industrial was likely to indicate less likely decrease in variety. Distance to commercial use was also a factor though it fell in terms of its importance from the earlier time period when it strongly influenced the likelihood of decrease in variety. Distance from open land use had opposite effects in the two time periods. In 1962-90 the further a cell was from open land use the more likely it was to lose variety. Population also had opposite effects in the two periods – higher population meant the likelihood of decrease in variety during the latter time period though high employment in a cell meant this decrease was less likely and had a stronger effect in terms of the coefficient.

Distance to highway was significantly likely to decrease variety in both time periods. Also, during the latter time period distance from railways was less likely to decrease in variety. High road density was also likely to result in a decrease in land use variety during the latter time period. Distance from the CBD was significant only in the latter time period and indicated that cells close to the CBD were more likely to lose variety. On the other hand locations close to district centers were less likely to lose variety during 1990-99 though they did tend to lose variety in the earlier time period. These trends tend to echo the land use intensity change trends to a large extent.

Clearly, the results indicate that the infrastructure of roads and railroads, along with current land uses, did impact the land use changes in terms of both intensity and variety, and in both time periods. While the period between 1962 and 1990 followed the conventional trends of densification of land use close to highways and in locations with high road density, the opposite trends were observed in 1990-99. The results also appear to indicate that the city is currently intensifying away from the CBD, highways, roadways and district centers into locations with poorer infrastructure. It also appears to indicate a loss of variety as land use homogenizes in most grid cells. The results of the simulation model discussed earlier were at a regional scale with a different data source and they appear to confirm these trends to some extent. However, we do need to confirm these results by obtaining more detailed data for the surrounding areas (which in the case of Delhi, spill over into the neighboring states).

We also linked the land use changes in the first period to those in the second time period through hierarchical choice models that assume that land use change in the 1990-99 period is conditional on those in 1962-90. However the results indicated that this was not a valid assumption. However, it is likely that a shorter time period such as 1990-95 could be linked with 1995-2000 since the growth in Delhi during this time period was more rapid. More data needs to be collected in order to test this theory.

POLICY IMPLICATIONS AND CONCLUSIONS

The 2001 Master Plan for New Delhi (*20*) estimates a population of 12.8 million people in 2001 living in a low-rise high-density city. This Master Plan intended to minimize the average trip lengths and introduce a five-tier system of commercial activities to accommodate required shopping, commercial offices and recreational needs. It included the provision of district centers to serve as a focal point for multi-nodal activities. By contrast, the 2001 Census indicates that the population of the city of New Delhi alone is 14 million (with an estimated agglomeration of 17 million in the surrounding metropolitan area). The densities are extremely high (about 25,000 persons per sq km). The five-tier system of commercial activity hierarchy has not been implemented and the variety of land uses appears to be falling which will result in higher trip lengths. Our model results indicate that this trend will continue as the current levels of urbanization continue. Tiwari (*21*) notes that, while mixed land use has curbed the numbers and lengths of primary non-work related trips, the number of trips per household for different purposes remain constant regardless of where the person lives. Nearly 28% of the population, with an income below Rs 2000 per month, can only depend on non-motorized modes. There is no pedestrian or bicycle plan in place to meet the needs of these people. Sarna et al (*9*) note that Delhi has the largest number of buses in any city in the world. About 5,000 buses were plying on the roads in 1985, approximately three times the number that were there in 1973, with the current figure estimated to be about 10,000 (*22*). However, the road system is reaching the maximum level of its ability to accommodate buses and traffic management measures such as high occupancy and bus only lanes may be a necessity to attain reasonable speeds beyond the very low speeds projected for current motorization growth rates (*21*).

The spatial effects of the land use change models are mapped in Figures 9 and 10. The map indicates that the probability of land use change in terms of both intensification and variety loss predicted by the changes in the last 10 years are much higher than those predicted for the model estimated for 1962-1990. Thus, Delhi faces not only expansion in terms of its city limits as indicated by the results of the CA simulation model, but also intensification in the use of its land area. Clearly, this will eventually impact the air quality of New Delhi as the numbers of people traveling continues to grow. Air quality is now a major concern with TSP (Total Suspended Particulates) levels being dangerously high (*23*). Currently, average annual levels in Delhi of both PM10 and TSP tend to be well above the National Ambient Air Quality Standards (Figure 10). Thus the locations of land use change are also locations of poor air quality and as travel needs intensify the prospects for improved air quality appear to be poor.

The data and the models indicate that industrial and office location, highway location, road density and district center locations are all significant in affecting land use change. The question to be asked in Delhi, as in most developing countries is: who is planning for these characteristics that affect land use change? The Master Planning process in New Delhi is not inclusive of the community, nor is it even guided by data collection. The current plan for 2020, like its predecessor, does not appear to be guided by a concerted effort on the part of the several agencies in Delhi responsible for planning. There have been no visible attempts to collect relevant data, make it available to the public, and advocate the interests of all those living in the metropolitan area. The lack of reliable data is a major drawback to this and other studies of Indian cities. Recent data for even simple transportation and land-use planning exercises such as origin-destination studies and transit surveys are not readily available. Our research, even with limited data, is able to show that land use changes are happening rapidly and are impacted by infrastructure such as highways, roads and railways and current location of industrial and office use.

Other studies *(24)* have shown that urban form is linked to air quality in developed cities. Preliminary results of regression models linking TSP to land use characteristics and weather conditions for New Delhi indicate that there is land use characteristics of the location where the air quality is measured is significant in affecting air quality as measured through ambient TSP levels. However, in the absence of relevant traffic counts and other transportation data these models remain preliminary. Clearly, there is a need for similar studies linking land use and transportation in a coherent fashion. Further, as more data becomes available publicly as part of the planning process, these models could be linked with transportation and air quality dispersion models to predict the future locations of environmental “hot-spots” in the city. This idea needs to be incorporated into a data-based land use and transportation plan for New Delhi.

Acknowledgement: This work is part of a project on Transportation, Land use and the Environment in India funded by a grant from the Ford Motor Company and the Harvard University Committee for Environment.

REFERENCES

1. World Health Organization (WHO) and United Nations Environment Programme. *Urban Air Pollution in Megacities of the World.* Blackwell publishers, Cambridge MA, 1992.
2. Mohan, D. and G. Tiwari. Mobility, environment and safety in megacities: dealing with a complex future. *IATSS Research*, Vol. 24, No. 1, 2000, pp. 39-46.
3. Gakenheimer, R. Urban mobility in the developing world. *Transportation Research Part A*, Vol. 33, 1999, pp. 671-689.
4. Kessler, J. and W. Schroeer. Meeting mobility and air quality goals: strategies that work. *Transportation*, Vol. 22, 1995, pp. 241-272.
5. Bartholomew, K. A. A Tale of two cities. *Transportation*. Vol. 22, 1995, pp. 273-293.
6. Gakenheimer, R. Land use/Transportation planning: new possibilities for developing and developed countries. *Transportation Quarterly*, Vol. 47, No. 2, 1993, pp. 311-322.
7. Mayer, H. M. *The spatial expression of urban growth*. Resource Paper 7. American Association of Geographers, New York, NY, 1969.
8. Warren, W. D. A transportation view of the morphology of cities. *Transportation Quarterly,* Vol. 47, No. 3, 1993, pp. 367-377.
9. Sarna, A. C. and S. M. Sarin. Transportation planners dilemma – Modal split and its manipulation. *Indian Highways*, January 1985, 5-18.
10. Ji, C. Y., Liu, Q. H., Sun, D. F., Wang, S., Lin, P. and X. W. Li. Monitoring urban expansion with remote sensing in China. *International Journal of Remote Sensing*, Vol. 22, No. 8, 2001, pp. 1441-1455.
11. Kundu, S. N., Sahoo, A. K., Mohapatra, S. and R. P. Singh. Change analysis using IRS-P4 OCM data after the Orissa super cyclone. *International Journal of Remote Sensing.* Vol. 22, No. 7, 2001, pp. 1383-1389.
12. Serneels, S and E. F. Lambin. Proximate causes of land-use change in Narok District, Kenya: a spatial statistical model. *Agriculture Ecosystems & Environment*, Vol. 85, No. 1-3, 2001, pp. 65-81.
13. Fischer, G. and L. X. Sun. 2001. Model based analysis of future land-use development in China. *Agriculture Ecosystems & Environment*, Vol. 85, No. 1-3, pp. 163-176.
14. Walker, R. Urban sprawl and natural area encroachment: linking land cover change and economic development in the Florida Everglades. *Ecological Economics*, Vol. 37, No. 3, 2001, pp. 357-369.
15. Clarke K. C. and L. J. Gaydos. Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. *International Journal of Geographical Information Systems*, Vol. 12, No. 7, 1998, pp. 699-714.
16. Wang, Y. Q. and X. S. Zhang. A dynamic modeling approach to simulating socioeconomic effects on landscape changes. *Ecological Modelling*, Vol. 140, No. 1-2, 2001, pp. 141-162.
17. Zhang, M. and J. D. Landis. *An empirical model of land use change in the San Francisco Bay Area: 1985-1990.* Working paper 646. Institute of Urban and Regional Development, University of California at Berkeley, 1995.
18. Chomitz, K. and D. Gray. Roads, Land Use, and Deforestation: A Spatial Model Applied to Belize. *World Bank Economic Review.* Vol. 10, No. 3, 1996, pp. 487-512.
19. Sheehan, M. O' Meara. City Limits: Putting the Brakes on Sprawl. World Watch Institute, Washington D.C. 2001.
20. Delhi Development Authority. *Master Plan for Delhi.* 1990.
21. Tiwari, G. 1999. Planning for non motorized traffic a prerequisite for sustainable transport system. IATSS Research. Vol. 23, No. 2, 1999, pp. 70-77.
22. Kokaz, K., Harshadeep, N. R., Rogers, P. and S. Srinivasan. A Simulation Analysis of Transportation Policies on Health and Environment in Delhi, India. *Proceedings of the 7th international conference on Computers in Urban Planning and Urban Management*, July 2001. University of Hawaii, Honolulu.

23. Central Pollution Control Board. Air quality data. http://envfor.nic.in/cpcb/cpcb.html. 2000. New Delhi, India.
24. Manins, P.C., Cope, M.E., Hurley, P.J., Newton, P.W., Smith, N.C. and L.O. Marquez. The impact of urban development on air quality and energy use. *Proceedings of the 14th International Clean Air & Environment Conference*, October 1998, pp 331-7. Melbourne, Australia.

LIST OF FIGURES

TABLE 1 Land use change and variety variables in the dataset

Value	**1962-1990**	**1990-1999**
Land use intensified (up)	1004 (31.3%)	1500 (49.0%)
Land use did not intensify	2205 (68.7%)	1562 (51.0%)
Land use de-intensified (down)	547 (17.1%)	864 (28.2%)
Land use did not de-intensified	2662 (82.9%)	2198 (71.8%)
Land use variety went up	1689 (52.6%)	236 (7.7%)
Land use variety did not go up	1520 (47.4%)	2826 (92.3%)
Land use variety went down	827 (25.8%)	2734 (89.3%)
Land use variety did not go down	2382 (74.2%)	328 (10.7%)

TABLE 2 Logit model estimated for land use change upwards 1962-1990

Independent Variable	**Estimated Coefficient**	**Standard Error**	**t- Statistic**
Constant	3.18**	0.59	5.37
Initial use residential	-5.21**	0.51	-10.21
Initial use open	-6.36**	0.51	-12.45
Distance to commercial land use (per km)	22.54**	10.43	2.16
Distance to industrial land use (per km)	22.56**	6.96	3.24
Average distance to highway (per km)	-8.83**	3.88	-2.28
Average distance to railroads (per km)	7.23	5.78	1.25
Average distance to CBD (per km)	7.27**	1.79	4.05
Average distance to district centers (per km)	15.91**	4.11	3.87
Road density (per sq. km)	1.11e-003**	2.24e-004	4.94
Population in 1960	2.99e-004**	1.21e-004	2.48
Number of grid cells		3209	
Percent correctly predicted		76.53	
^{2}		0.35	

TABLE 3 **Logit model estimated for land use change upwards 1990-1999**

Independent Variable	**Estimated Coefficient**	**Standard Error**	**t- Statistic**
Constant	6.23**	0.50	12.36
Initial use residential	-6.23**	0.39	-16.02
Initial use open	-5.95**	0.40	-14.81
Distance to commercial land use (per km)	-31.33*	16.99	-1.84
Distance to industrial land use (per km)	-55.15**	10.28	-5.37
Average distance to highway (per km)	-2.97	4.97	-0.59
Average distance to railroads (per km)	37.49**	5.98	6.27
Average distance to CBD (per km)	-9.05**	2.12	-4.25
Average distance to district centers (per km)	28.97**	5.57	5.19
Road density (per sq. km)	-1.09e-003**	2.81e-004	-3.88
Population in 1991	2.11e-004**	3.86e-005	5.46
Employment in 1991	-6.99e-004**	1.28e-004	-5.46
Number of grid cells		3062	
Percent correctly predicted		86.67	
^{2}		0.53	

TABLE 4 Logit model estimated for land use change downwards in variety 1962-1990

Independent Variable	**Estimated Coefficient**	**Standard Error**	**t- Statistic**
Constant	1.23**	0.31	4.01
Initial use residential	-0.43**	0.15	-2.84
Initial use open	-0.34**	0.16	-2.15
Initial use industrial	-0.29*	0.17	-1.73
Distance to commercial land use (per km)	47.53**	11.16	4.26
Distance to residential land use (per km)	-0.01**	13.47	-8.95
Distance to open land use (per km)	51.56**	20.02	2.57
Average distance to highway (per km)	6.49*	3.67	1.78
Average distance to railroads (per km)	-2.14	4.76	-0.44
Average distance to CBD (per km)	-1.19	1.62	-0.73
Average distance to district centers (per km)	63.97**	4.96	12.90
Road density (per sq. km)	0.00004	0.0002	-0.23
Population in 1960	-0.0004	0.0001	-3.68
Number of grid cells		3209	
Percent correctly predicted		75	
^{2}		0.23	

TABLE 5 **Logit model estimated for land use change downwards in variety 1990-1999**

Independent Variable	**Estimated Coefficient**	**Standard Error**	**t- Statistic**
Constant	-4.57	0.43	-10.50
Initial use residential	0.01	0.27	0.05
Initial use open	0.39	0.24	1.63
Initial use industrial	-2.84**	1.02	-2.76
Distance to commercial land use (per km)	0.02**	24.06	9.88
Distance to residential land use (per km)	0.04**	26.78	10.64
Distance to open land use (per km)	-54.29**	21.11	-2.57
Average distance to highway (per km)	14.99**	7.13	2.10
Average distance to railroads (per km)	-19.87**	8.47	-2.34
Average distance to CBD (per km)	17.14**	2.81	6.10
Average distance to district centers (per km)	-65.32**	10.59	-6.17
Road density (per sq. km)	0.002**	0.0003	6.27
Population in 1991	0.0003**	0.00005	5.63
Employment in 1991	-0.001**	0.0002	-6.13
Number of grid cells		3062	
Percent correctly predicted		91	
^{2}		0.72	