

# AREA-BASED MODELS OF NEW HIGHWAY ROUTE GROWTH

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**Abstract**      Empirical data and statistical models are used to answer the question of where the new highway routes are most likely to be located. High-quality land-use, population distribution and highway network GIS data for the Twin Cities Metropolitan Area from 1958 to 1990 are developed for this study. The highway system is classified into three levels, Interstate highways, divided highways, and secondary highways. Binary logit models estimate the new route growth probability of divided highways and secondary highways. Interstates, however, are not modeled here and are used as a predictor in modeling the growth of divided highways and secondary highways. The results show that the area's land-use attributes and population density level do have significant relationship with the area's likelihood of adding new highway routes.

**Keywords**      network growth, hierarchy of roads, land-use, population, GIS.

## 1. INTRODUCTION

Transportation networks shape cities and speak to people's everyday lives. Despite their long existence and constant variation, researchers seldom question how the networks have evolved to their current configurations and what were the factors leading or related to transportation network growth. Transportation networks have simply been assumed to be results of top-down decision-making, and based on that belief, the future growth and evolution of transportation networks are taken to be subjectively decided by the planners and policy-makers.

Few previous studies deal with the problem of transportation network growth. Garrison and Marble (1965) investigate a collection of tools (both statistical models and mathematical models) for forecasting the development of transportation. Their studies include both the analysis of aggregates (such as the comparison among nations for railroad passenger and freight movements and the demand for freight transportation in US) and the analysis of network structure characteristics (using graph theory and nearest neighbor methods). They observed connections to the nearest large neighbor explained the order rail network growth in Ireland. Taaffe et al. (1963) study the economic, political and social forces behind infrastructure expansion in underdeveloped countries. Their study finds that initial roads are developed to connect regions of economic activity and lateral roads are built around these initial roads. Yamins et al. (2003) present a simulation of road growing dynamics that can generate global features as belt-ways and star patterns observed in urban transportation infrastructure. The road growing dynamics consist of two steps: Identifying the maximum transportation potential between two locations within the city, followed by the generation of the least expensive road between these two locations.

This paper constitutes a portion of a larger research project to understand the evolution of transportation networks at a theoretical and empirical level, recognizing the inter-dependence of supply and demand, and to develop agent-based models to replicate that process. Of the recently conducted studies, Karamalaputi and Levinson (2002) estimated a logit model to predict the likelihood of expanding a highway in the Twin Cities using data from the past 20 years, and considering cost and the effects of expanding a link on its upstream and downstream neighbors, as well as on parallel links. Yerra and Levinson (2003) developed a simulation model to visualize network growth. Their model captures the dynamics that lead to a hierarchical arrangement of roads for a given network structure and land use distribution and show that hierarchies are intrinsic properties of networks. The results also show that roads, specific routes with continuous attributes, are emergent properties of transportation networks.

In this study, empirical data and statistical models are used to find the answer to the question of where the new highway routes are most likely to be located. There are various factors contributing to the route selection of new highways, such as the state of the economy, jurisdictional boundaries, geographical balance policies, land-use requirements, population density constraints, and politics. But of these factors, some are very special and applicable only to very limited regions and some are very difficult to trace down in data collection. So finally, the factors of land-use distribution and population density are contained in the model as predictor variables, because these two factors describe the basic regional economic characteristics and we have well-developed land-use and population distribution GIS data for the Twin Cities Metropolitan Area from 1958 to 1990.

The highway system for the Twin Cities Metropolitan Area from 1958 to 1990 can be classified into three levels, Interstate highways, divided highways, and secondary highways (the growth of local streets that serve the function of land access rather than movement is not estimated). Binary logit models estimate the new route growth probability of divided highways and secondary highways in geographical cells based on land-use, population distribution and highway network data for the base years. Interstates, however, are not modeled here and will only be qualitatively analyzed because the Interstate system was developed for the nation in its entirety and at a minimum requires a larger geographic scope. Interstates are used as a predictor in modeling the growth of divided highways and secondary highways.

In the following sections, we first describe the data for this study, and then present the hypotheses, statistical models and results for divided highways and secondary highways respectively. Finally conclusions are drawn.

## **2. DATA**

High-quality GIS maps from paper maps are developed for this study which are summarized in Table 1. The study period began with 1958 when the earliest land-use map was created for the Twin Cities Metro Area. Both land-use and census data were issued decennially.

Then a lattice layer composed of 30,729 square cells ( $0.141 \text{ km}^2$ ) is created, which shares the same corridor system with land-use, population distribution and highway network layers. Each of the population distribution layers, land-use layers, and highway network layers are merged into the lattice layer (Figure 1), so that each cell of the lattice layer

contains the spatial information of population, land-use and highways. Figures 2 and 3 show the gridded 1978 Land-Use layer and 1980 Population Distribution layer.

Now each of the cells can be viewed as one observation. Land-use, population distribution and highway network data from the base years and highway network data from the predicted years will be fitted into the models to estimate the new highway growth probability. The models are estimated for the new highway growth probability of three-year, five-year, and ten-year respectively. Table 2 summarizes the base years' data and the predicted years' data.

### **3. DIVIDED HIGHWAYS**

#### **3.1 Hypotheses**

Divided highways are separated highways for traffic moving in opposite directions. They are the second level in the hierarchy of the highway system (below Interstates) and mainly serve local commuting traffic. Hypotheses of the growth tendency of divided highways are presented as follows.

**Agglomeration.** Agglomeration is the phenomenon of roads of a particular class to be built near (or connecting to) similar roads. The agglomeration growth of divided highways includes both the emergence of alternative routes and also the extension of the existing corridors. First, as major commuting corridors, divided highways typically locate at or close to regions with relatively intense economic activities. Moreover, divided highways may lead to further economic development nearby, which means more traffic demand in the neighborhood of the existing corridors. Therefore, when the existing routes show rising demand, neighboring cells should have a high likelihood of alternative route

development. Second, the requirement of connectivity induces the further extension of existing corridors or the addition of new links adjoining the old ones. After new routes (the alternative routes and/or the extension routes) appear, the boosted economic activity and traffic growth nearby may lead to another round of agglomeration growth.

*Generally we expect that the neighboring cells of the existing divided highways should be associated with a higher route growth probability.* To test the hypothesis of agglomeration, a 0.5-kilometer buffer area of the existing divided and undivided highways is made (The reason for including undivided highways is that undivided highways have the highest probability of upgrading into divided highways.). Variable  $A$  is defined as  $A = 1$  if the observed cell is within or intersects the buffer area, otherwise  $A = 0$ . The cells with  $A=1$  should be associated with a higher growth probability than the cells with  $A = 0$ .

**Population density.** *We expect that low and medium populated areas should be associated with a higher route growth probability, while both the sparsely populated areas and the highly populated areas should have a lower growth probability.* For the high density areas, although their neighboring areas may have more traffic demand, they are usually associated with high land-prices and costly relocation. Therefore, the final decision of route development in the high density areas should be the balance of demand, costs and the availability of cheaper alternative routes. Cells are classified into four groups,  $P_S$  (sparsely populated area),  $P_L$  (low population area),  $P_M$  (medium population area), and  $P_H$  (high population area). Table 3 lists the population per cell for  $P_S$ ,  $P_L$ ,  $P_M$ , and  $P_H$ .

**Employment zones.** As mentioned before, divided highways mainly serve local commuting traffic. Therefore, *we expect the further growth of divided highways should also tend to be close to employment zones.* To test this hypothesis, variable  $U_E$  is defined as  $U_E =$

1 if the observed cell is within or intersects employment zones, otherwise  $U_E = 0$ . The cells with  $U_E = 1$  should have a higher probability of divided highway growth than the cells with  $U_E = 0$ .

**Commercial zones.** *We expect that commercial zones and their neighborhood should have high network growth probability.* To test this hypothesis, variable  $U_C$  is defined as  $U_C = 1$  if the observed cell is within or intersects commercial zones, otherwise  $U_C = 0$ . The cells with  $U_C = 1$  should have a higher probability of divided highway growth than the cells with  $U_C = 0$ .

**Agricultural areas.** Variable  $U_A$  is defined as the percentage of agricultural areas within each cell, and *we expect that  $U_A$  should be negatively associated with route growth.* However, it should be noted that although agricultural areas typically have low traffic demand, they are also the areas of low land-prices; furthermore, one purpose of divided highways is to connect urban and suburban areas and spur economic development of the undeveloped areas. These factors may lead to route growth in the agricultural areas.

**Water areas.** Water is a barrier for highway development. Variable  $U_W$  is defined as the percentage of water area within each cell, and *we expect that  $U_W$  should be negatively related to route growth.*

### 3.2 Model

A binary logit model is estimated to predict the divided highway growth based on the population distribution, land-use and highway network data of the base years. It should be noted that the model estimates the probability of divided highway growth in each cell, but it does not estimate the extent of growth. The extent of growth is influenced by many factors (such as the direction of the highway segment, the path to cross the cells, the connection with

other links and other factors such as the geographical or geological conditions, etc.) that cannot be controlled in this study. The problem of extent will be addressed in future research.

To diagnose potential multicollinearity, we examined the correlations among the variables and none of them was larger than 0.60. We did not find the symptoms of multicollinearity (such as inflated standard errors, excessive logit iterations (more than 10 or 15 times) or unreasonable statistical results of the critical independent variable(s), etc). So multicollinearity should not cause disturbance in this case. Of the models tested, the following model is the best in overall model fit, and the regression results of the model are presented in Table 4.  $G_D = f(P_S, P_L, P_M, P_H, A, U_E, U_C, U_A, U_W, L_b, L_D, L_U, L_S, D, Y)$

Where,  $G_D$  (Dependent Variable) - Divided Highway Growth, if from the base year to the predicted year there is growth in divided highways in the observed cell,  $G_D = 1$ , otherwise  $G_D = 0$ .

$P_S, P_L, P_M$ , and  $P_H$  - Population predictors. All the cells are classified into four groups,  $P_S$  (sparsely populated area),  $P_L$  (low population area),  $P_M$  (medium population area), and  $P_H$  (high population area).

$A$  - Agglomeration predictor, if the observed cell is within or intersects the 0.5-kilometer buffer area of the divided and undivided highways of the base year,  $A = 1$ , otherwise  $A = 0$ .

$U_E, U_C, U_A$ , and  $U_W$  - Land-use predictors. They are defined as follows:

$U_E$  - If the observed cell is within or intersects employment zones (including airports) of the base year,  $U_E = 1$ , otherwise  $U_E = 0$ ;

$U_C$  - If the observed cell is within or intersects commercial areas of the base year,  $U_C = 1$ , otherwise  $U_C = 0$ ;

$U_A$  - The percentage of agricultural areas within each cell;

$U_W$  - The percentage of water areas within each cell.

$L_I$ ,  $L_D$ ,  $L_U$ , and  $L_S$  – the base years' highway length within each cell. There are four levels of highways:  $L_I$  (the kilometers of Interstates),  $L_D$  (the kilometers of Divided Highways),  $L_U$  (the kilometers of Undivided Highways), and  $L_S$  (the kilometers of Secondary Highways).

$D$  – The distance from the center of each cell to the nearest CBD; there are two CBDs, Minneapolis CBD and St. Paul CBD.

$Y$  – The dummy variable of the base year.

### 3.3 Results

For three predictions in Table 4, the overall model is significant at the .01 level according to the Model chi-square statistic, and the model predicts more than 98% of the responses correctly. The McFadden's  $R^2$  ranges from 0.13 to 0.19. The results of the predictors that test the hypotheses are summarized as follows:

For Population Groups ( $P_S$ ,  $P_L$ ,  $P_M$ , and  $P_H$ ), the group with the lowest population density  $P_S$  was dropped due to collinearity. The high density group  $P_H$  always has negative and significant results, which indicates that the high density areas have lower divided highway growth probability than other areas. The low density group  $P_L$  and medium density group  $P_M$  are always positive and significant, which indicates that low and medium populated areas have higher divided highway growth probability than other areas. These results accord with our hypothesis.

The coefficient on  $A$  is positive and significant for all the three predictions, which indicates that the new divided highways were more likely to emerge in the neighborhood of the existing corridors, and these results accord with the hypothesis of agglomeration tendency, the neighborhood of the existing corridors should be more likely to have new route development. Also for the three-year growth prediction  $U_E$  has the highest odds ratio 2.618, which means that the neighborhood of the existing corridors are 2.618 times more likely to have divided highway development than other regions.

$U_E$  is positive for all the three predictions and significant for the three-year growth prediction. Since the closer the prediction the more accurate the result, we think this result generally supports the hypothesis that employment zones (including airports) have a higher likelihood of divided highway growth than other regions.

$U_C$ , is positive and significant for all the three predictions, which indicates that commercial zones are related to a higher likelihood of divided highway growth than other regions.

$U_A$  is negative and insignificant in the three-year and ten-year growth predictions and positive and insignificant in the five -year growth prediction, which means that agricultural areas are not necessarily associated with low (or high) divided highway growth probability. We generally expect agricultural areas to be related to low growth probability since there is less traffic demand in these areas. But this can be overruled if the purpose of divided highway development is to connect urban and suburban areas and to spur economic development of the undeveloped areas. In addition, diverting from the highly urbanized areas saves construction costs.

$U_W$  is negative and significant for all the three predictions, which supports the hypothesis that water areas should be negatively related to route growth.

$D$  is positive and significant for all the three predictions, which indicates that the farther from downtown the higher the likelihood of divided highway growth.

## 4. SECONDARY HIGHWAYS

### 4.1 Hypotheses

Secondary highways are less important than divided highways but more important than local roads, and composed of undivided highways and county highways. They are the longest in mileage but carry less traffic at slower speeds. The hypotheses about the growth of secondary highways are summarized as follows:

**Urban settlements.** Secondary highways serve local traffic, they are the proximate and ultimate connecting highways of urban settlements, so the growth of secondary highways should be related to the settlement areas, which include residential areas, commercial areas, industrial areas, institutions, offices, airports and transportation infrastructure. *We expect that the cells with larger settlement areas should be more likely to have secondary highway growth.* To test this hypothesis, the percentage of urban settlement areas within each cell is used as an independent variable  $U_S$ , and we expect this variable to be positively and significantly related to the probability of secondary highway growth.

**Percentage of water areas and agricultural areas within each cell.** *The percentage of water areas should be negatively related to the secondary highway growth probability, but we do not expect the similar relationship for agricultural areas.* Agricultural areas have the demand for product transport, and agricultural areas usually have no major (Interstate or

divided) highways, so secondary highways are the only commuting routes. On the one hand, the cells with a higher percentage of agricultural areas have less urban settlements and less traffic demand, which may lead to less secondary highway growth; on the other hand, however, secondary highways are more relied on in the agricultural areas for product transport and commuting service due to the lack of higher hierarchical highways, which may lead to secondary highway growth.

#### 4.2 Model

As with divided highways, logit models are used to predict the secondary highway growth based on the population distribution, land-use and highway network data of the base years. No multicollinearity symptom has been found in the results, so we conclude that multicollinearity is not a problem in this case. Of the models tested, the following model is the best in overall model fit, and the regression results of the model are presented in Table 5.

$$G_S = f(P_S, P_L, P_M, P_H, U_S, U_E, U_C, U_A, U_W, L_L, L_D, L_U, L_S, D, Y)$$

Where,

$G_S$  (Dependent Variable) - Secondary Highway Growth, if from the base year to the predicted year there is growth in secondary highways in the observed cell,  $G_S = 1$ , otherwise  $G_S = 0$ .

$U_S$  - The percentage of urban settlement within each cell; here, the urban settlement include residential areas, commercial areas, industrial areas, institutions, offices, airports and transportation infrastructure;

The definitions of the other predictors are the same as those for divided highways.

### 4.3 Results

Of the three predictions in Table 5, the overall model is significant at the .01 level according to the Model chi-square statistic, and the model usually predicts more than 90% of the responses correctly. The McFadden's  $R^2$  ranges from 0.05 to 0.08.

$U_S$  is always positive and significant, which supports our hypothesis that cells with larger settlement areas are more likely to have secondary highway growth. Both employment zones ( $U_E$ ) and commercial zones ( $U_C$ ) have a high likelihood of secondary highway growth. Water area and their neighborhood ( $U_W$ ) always have low probability of growth. The agricultural area ( $U_A$ ), however, is positive and significant for all the predictions which indicates that agricultural area is associated with a high likelihood of secondary highway growth, this result can be explained by the fact that secondary highways are more relied on in the agricultural areas for product transport and commuting service due to the lack of primary roads.

## 5. CONCLUSIONS

The study deals with the problem of the most probable new highway growth rule, which tells where the newly added highways are most likely to be located based on empirical research, and which has the highest probability of being reiterated in the real world. Empirical data are fitted into statistical models to find the most probable new route. The land-use, population distribution and highway network data of the Twin Cities Metropolitan Area from 1958 to 1990 are used. The highway system of this period can be classified into three levels, Interstate highways, divided highways, and secondary highways. Binary logit models estimate the new route growth probability of divided highways and secondary highways.

Interstates, however, are not modeled here and are used as a predictor in modeling the growth of divided highways and secondary highways.

The results show that the area's land-use attributes and population density level do have significant relationships with the area's likelihood of adding new highway routes. For divided highways, since they serve as the major local commuting routes, the new divided highway routes are more likely to be close to employment zones. Also commercial zones have a high likelihood of divided highway growth. Divided highway growth follows the agglomeration tendency, that is, the neighboring areas of the existing corridors have a higher likelihood of new route development. As to population density, low and medium density areas have higher divided highway growth probability than both the high density areas and the sparsely populated areas. Furthermore the farther from downtowns the higher the likelihood of divided highway growth.

For secondary highways, since they are the proximate and ultimate connecting highways of urban settlements, the growth of secondary highways is significantly related to the settlement areas, and the cells with a higher percentage of urban settlement area are more likely to have secondary highway growth. Both employment zones and commercial zones have a high likelihood of secondary highway growth. The agricultural areas are associated with a high likelihood of secondary highway growth, which may be due to agricultural areas' high reliance on secondary highways for product transport and commuting service.

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## TABLES AND FIGURES

**Table 1.** GIS data summary

| GIS Map   | Source  |
|---|---|
| Twin Cities Metropolitan Area Population Distribution 1960, 1970 and 1980                               | Twin Cities Metropolitan Area, 1960, 1970 and 1980 Census Tracts, issued by U.S. Census Bureau  |
| Twin Cities Metropolitan Area Land-Use Distribution 1958, 1968 and 1978                                 | Twin Cities Metropolitan Area, Generalized Land Use 1958, 1968 and 1978, issued by Twin Cities Metropolitan Council   |
| Twin Cities Metropolitan Area Highway Networks 1962, 1965, 1968, 1971, 1975, 1978, 1981, 1985, and 1990 | Minnesota Official Transportation Maps, issued by Minnesota Department of Transportation (* before 1978, it was called 'Minnesota Official Highway Maps' and 'Minnesota Department of Highway') |

**Table 2.** The base years' data and the predicted years' data used for model estimation

| <b>Three-Year New Highway Growth Probability Estimation</b>              |                                       |
|--|---------------------------------------|
| Base Years' Land-use, Population Distribution and Highway Network Data   | Predicted Years' Highway Network Data |
| 1968 Land-use,<br>1970 Population Distribution,<br>1968 Highway Network  | 1971 highway network                  |
| 1978 Land-use,<br>1980 Population Distribution,<br>1978 Highway Network  | 1981 highway network                  |
| <b>Five-Year New Highway Growth Probability Estimation</b>               |                                       |
| Base Years' Land-use, Population Distribution and Highway Network Data   | Predicted Years' Highway Network Data |
| 1958 Land-use,<br>1960 Population Distribution,<br>1962 Highway Network* | 1965 highway network                  |
| 1968 Land-use,<br>1970 Population Distribution,<br>1968 Highway Network  | 1975 highway network                  |
| 1978 Land-use,<br>1980 Population Distribution,<br>1978 Highway Network  | 1985 highway network                  |
| <b>Ten-Year New Highway Growth Probability Estimation</b>                |                                       |
| Base Years' Land-use, Population Distribution and Highway Network Data   | Predicted Years' Highway Network Data |
| 1958 Land-use,<br>1960 Population Distribution,<br>1962 Highway Network  | 1968 highway network                  |
| 1968 Land-use,<br>1970 Population Distribution,<br>1968 Highway Network  | 1978 highway network                  |
| 1978 Land-use,<br>1980 Population Distribution,<br>1978 Highway Network  | 1990 highway network                  |

*\* Note: 1958 Highway Network should be used as the base year data, but before 1962, the Twin Cities Metro Area just covered very small area in the Minnesota Official Highway Maps and more than half of the observations would be dropped if 1958 Highway Network were used. Therefore, 1962 Highway Network is used as a substitute.*

**Table 3.** The number of people per cell for  $P_S$ ,  $P_L$ ,  $P_M$ , and  $P_H$

| Population Group    | $P_S$ | $P_L$  | $P_M$   | $P_H$ |
|---------------------|-------|--------|---------|-------|
| Population per cell | 0~50  | 51~100 | 101~300 | >300  |

**Table 4.** Logit regression results for divided highway growth prediction

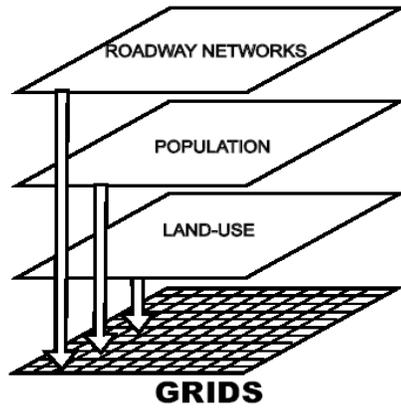
| Dependent Variable = $G_D$<br>Independent Variable | Logit Regression Results |         |       |                  |         |       |                 |         |       |
|--|--------------------------|---------|-------|------------------|---------|-------|-----------------|---------|-------|
|  | Three_Year_Growth        |         |       | Five_Year_Growth |         |       | Ten_Year_Growth |         |       |
|  | Odds Ratio               | Coef.   | P> z  | Odds Ratio       | Coef.   | P> z  | Odds Ratio      | Coef.   | P> z  |
| $P_L$  | 1.945                    | *0.665  | 0.000 | 2.192            | *0.785  | 0.000 | 2.013           | *0.699  | 0.000 |
| $P_M$  | 1.565                    | *0.448  | 0.004 | 1.868            | *0.625  | 0.000 | 1.579           | *0.457  | 0.000 |
| $P_H$  | 0.595                    | *-0.519 | 0.017 | 0.529            | *-0.636 | 0.000 | 0.408           | *-0.897 | 0.000 |
| $A$  | 2.618                    | *0.962  | 0.000 | 1.000            | *0.000  | 0.019 | 1.000           | *0.000  | 0.000 |
| $U_E$  | 1.213                    | *0.193  | 0.069 | 1.068            | 0.066   | 0.435 | 1.112           | 0.106   | 0.161 |
| $U_C$  | 1.711                    | *0.537  | 0.000 | 1.435            | *0.361  | 0.000 | 1.288           | *0.253  | 0.004 |
| $U_A$  | 0.845                    | -0.168  | 0.310 | 1.005            | 0.005   | 0.965 | 0.943           | -0.059  | 0.560 |
| $U_W$  | 0.204                    | *-1.590 | 0.004 | 0.152            | *-1.887 | 0.000 | 0.134           | *-2.010 | 0.000 |
| $L_I$  | 1.000                    | 0.000   | 0.988 | 1.000            | 0.000   | 0.532 | 1.000           | 0.000   | 0.650 |
| $L_D$  | 1.001                    | *0.001  | 0.002 | 1.002            | *0.002  | 0.000 | 1.002           | *0.002  | 0.000 |
| $L_U$  | 1.004                    | *0.004  | 0.000 | 1.005            | *0.005  | 0.000 | 1.004           | *0.004  | 0.000 |
| $L_S$  | 1.003                    | *0.003  | 0.000 | 1.003            | *0.003  | 0.000 | 1.002           | *0.002  | 0.000 |
| $D$  | 1.000                    | *0.000  | 0.029 | 1.000            | *0.000  | 0.002 | 1.000           | *0.000  | 0.000 |
| $Y_{58}$   |                          |         |       | 0.285            | *-1.256 | 0.000 | 0.443           | *-0.815 | 0.000 |
| $Y_{68}$   | 2.081                    | *0.733  | 0.000 |                  |         |       |                 |         |       |
| $Y_{78}$   |                          |         |       | 0.623            | *-0.473 | 0.000 | 0.603           | *-0.506 | 0.000 |
| Number of obs                                      | 48119                    |         |       | 63560            |         |       | 63560           |         |       |
| Prob > chi2  | 0.0000(14)               |         |       | 0.0000(15)       |         |       | 0.0000(15)      |         |       |
| Mcfadden's-R <sup>2</sup>                          | 0.19                     |         |       | 0.14             |         |       | 0.13            |         |       |
| % Correct Predictions                              | 98.93%                   |         |       | 98.54%           |         |       | 98.15%          |         |       |

\* Indicates that the coefficients are statistically significant at 0.10 level.

**Table 5.** Logit regression results for secondary highway growth prediction

| Dependent Variable = $G_s$ | Logit Regression Results |         |       |                  |         |       |                 |         |       |
|----------------------------|--------------------------|---------|-------|------------------|---------|-------|-----------------|---------|-------|
|                            | Three_Year_Growth        |         |       | Five_Year_Growth |         |       | Ten_Year_Growth |         |       |
| Independent Variable       | Odds Ratio               | Coef.   | P> z  | Odds Ratio       | Coef.   | P> z  | Odds Ratio      | Coef.   | P> z  |
| $P_L$                      | 2.064                    | *0.725  | 0.000 | 1.604            | *0.473  | 0.000 | 1.736           | *0.552  | 0.000 |
| $P_M$                      | 2.066                    | *0.726  | 0.000 | 1.546            | *0.436  | 0.000 | 1.462           | *0.380  | 0.000 |
| $P_H$                      | 2.592                    | *0.952  | 0.000 | 1.338            | *0.291  | 0.003 | 1.280           | *0.247  | 0.002 |
| $U_S$                      | 1.340                    | *0.293  | 0.080 | 1.634            | *0.491  | 0.000 | 1.802           | *0.589  | 0.000 |
| $U_E$                      | 1.375                    | *0.318  | 0.000 | 1.281            | *0.247  | 0.000 | 1.230           | *0.207  | 0.000 |
| $U_C$                      | 1.269                    | *0.238  | 0.008 | 1.195            | *0.178  | 0.009 | 1.136           | *0.128  | 0.033 |
| $U_A$                      | 1.349                    | *0.300  | 0.050 | 1.428            | *0.356  | 0.001 | 1.517           | *0.417  | 0.000 |
| $U_W$                      | 0.094                    | *-2.360 | 0.000 | 0.373            | *-0.987 | 0.000 | 0.365           | *-1.007 | 0.000 |
| $L_I$                      | 1.001                    | *0.001  | 0.053 | 1.000            | 0.000   | 0.266 | 1.000           | 0.000   | 0.732 |
| $L_D$                      | 1.001                    | *0.001  | 0.090 | 1.000            | 0.000   | 0.126 | 1.000           | 0.000   | 0.627 |
| $L_U$                      | 1.002                    | *0.002  | 0.000 | 1.001            | *0.001  | 0.000 | 1.001           | *0.001  | 0.000 |
| $L_S$                      | 1.001                    | *0.001  | 0.000 | 1.001            | *0.001  | 0.000 | 1.001           | *0.001  | 0.000 |
| $D$                        | 1.000                    | *0.000  | 0.001 | 1.000            | 0.000   | 0.106 | 1.000           | *0.000  | 0.000 |
| $Y_{58}$                   |                          |         |       | 0.731            | *-0.314 | 0.000 | 2.137           | *0.759  | 0.000 |
| $Y_{68}$                   | 2.346                    | *0.853  | 0.000 |                  |         |       |                 |         |       |
| $Y_{78}$                   |                          |         |       | 0.342            | *-1.073 | 0.000 | 0.482           | *-0.729 | 0.000 |
| Number of obs              | 48119                    |         |       | 63560            |         |       | 63560           |         |       |
| Prob > chi2                | 0.0000(14)               |         |       | 0.0000(15)       |         |       | 0.0000(15)      |         |       |
| McFadden's-R <sup>2</sup>  | 0.06                     |         |       | 0.05             |         |       | 0.08            |         |       |
| % Correct Predictions      | 97.55%                   |         |       | 95.89%           |         |       | 93.91%          |         |       |

\* Indicates that the coefficients are statistically significant at 0.10 level.



**Figure 1.** Merging Layers

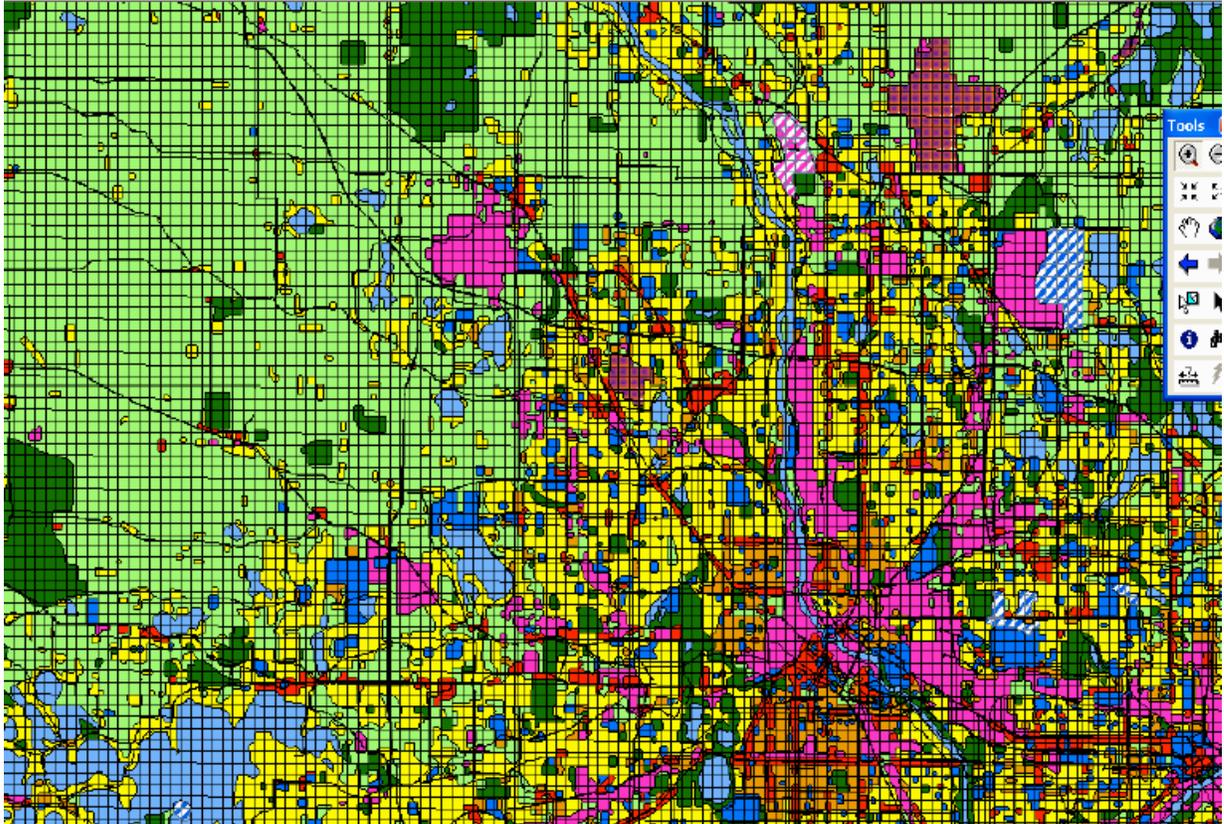
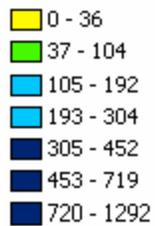
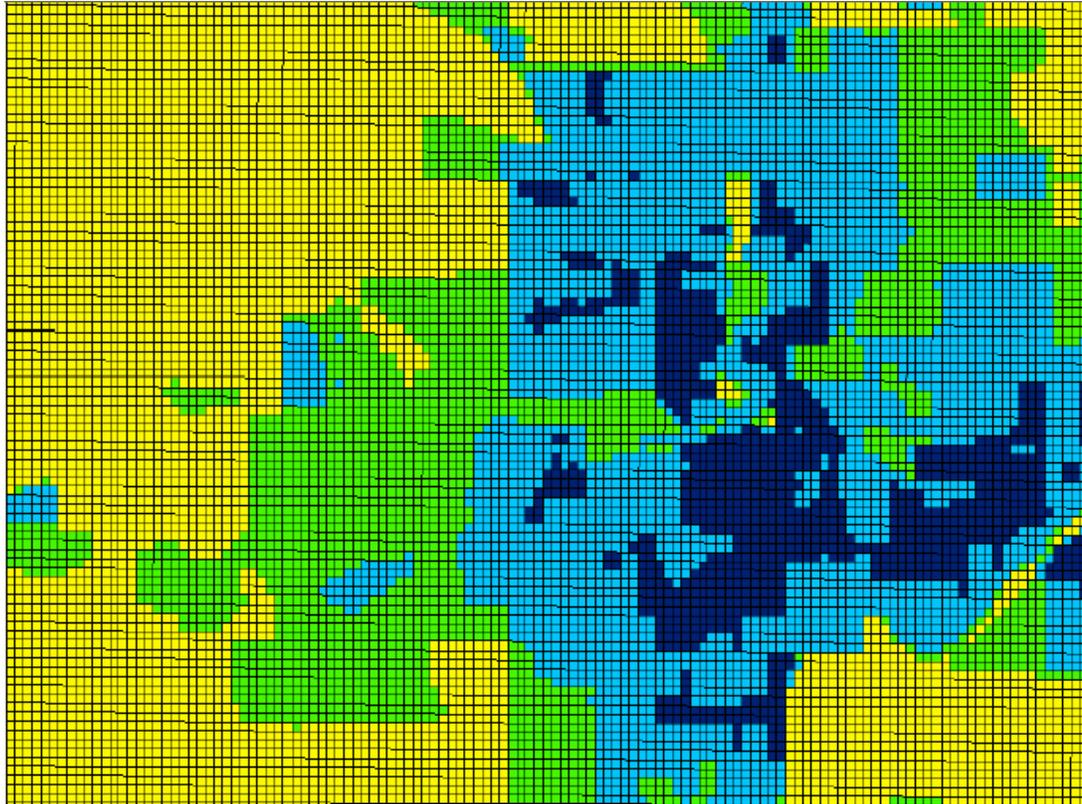


Figure 2. The gridded Land-Use layer

**1978 Population Distribution**





**Figure 3.** The gridded Population Distribution layer