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Highway Improvements and Land Development Patterns in the Greater Twin Cities Area, 1970–1997: Measuring the Connections

Report #8 in the Series:
Transportation and Regional Growth Study

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The authors remain fully responsible for any errors in fact.

Preface

The Transportation and Regional Growth Study is a research and educational effort designed to aid the Twin Cities region in understanding the relationship of transportation and land use. Many regions of the country are experiencing rapid commercial and residential development, often accompanied by population growth and growth in the total area of land developed. This has caused a range of concerns, including the direct costs of the infrastructure needed to support development and the social and environmental side effects of development patterns.

This study is an effort to better understand the linkages between land use, community development, and transportation in the Twin Cities metropolitan area. It is designed to investigate how transportation-related alternatives might be used in the Twin Cities region to accommodate growth and the demand for travel while holding down the costs of transportation and maximizing the benefits. The costs of transportation are construed broadly and include the costs of public sector infrastructure, environmental costs, and those costs paid directly by individuals and firms. Benefits are also broadly construed. They include the gains consumers accrue from travel, the contribution of transportation and development to the economic vitality of the state, and the amenities associated with stable neighborhoods and communities.

The University of Minnesota's Center for Transportation Studies is coordinating the Transportation and Regional Growth Study at the request of the Minnesota Department of Transportation and the Metropolitan Council. The project has two components. The first is a research component designed to identify transportation system management and investment alternatives consistent with the region's growth plans. It has six parts:

1. Twin Cities Regional Dynamics
2. Passenger and Freight Travel Demand Patterns
3. Full Transportation Costs and Cost Incidence
4. Transportation Financing Alternatives
5. Transportation and Urban Design
6. Institutional and Leadership Alternatives

The first three research areas are designed to gather facts about the transportation system and its relationship to land use in the Twin Cities metropolitan area. The other three research areas will use these facts to investigate alternatives in financing, design, and decision making that could have an impact on this relationship. Results of this research is and will be available in a series of reports published for the Transportation and Regional Growth Study.

The study's second component is a coordinated education and public involvement effort designed to promote opportunities to discuss the relationship between transportation and growth based on the research results. It is believed that this dialogue will help increase knowledge and raise the level of awareness about these issues among the study's many audiences including decision makers who make policy, agency professionals who implement policy, stakeholder groups who try to influence policy, and members of the general public who experience the consequences of those policies.

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Executive Summary

Ongoing land development and rapid population growth in the Twin Cities region have generated many questions. Among those are:

- How are improvements in highway transportation infrastructure and patterns of land development in suburban and exurban areas of the Greater Twin Cities area associated?
- Do road improvements encourage land development, or is it the other way around?
- Do cause-effect relationships that link the two remain constant through the decades, or have they changed over the last 30 years?

These issues are explored in this report, in which we examine highway improvements and land development throughout 24 Minnesota and Wisconsin counties over three decades. Specifically, the report examines the link between transportation and four types of land development: residential, industrial, commercial, and office. Correlations between the timing of land development and the timing of transportation improvements for each of the four land development types also were studied, as were the processes in which development seems to follow, as well as lead, highway transportation improvements.

The report's findings suggest that the impact of major highway improvements on land development patterns took one form in the 1970s, another in the 1980s, and still other forms in the 1990s. Study findings also illustrate how the lead-lag relationships differ by development type. The breadth of information in the study will be used to create guidelines to maximize future highway and land development.

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Chapter 1

Why are Transportation Infrastructure and Development Activity Likely to Be Related?

Highway Improvements and Land Development through the Years

The question is often asked: how are improvements in highway transportation and patterns of land development in suburban and exurban areas associated [1]? Do road improvements encourage land development? Or is it the other way around? Do the cause-effect relationships that link the two remain constant through the decades? Or have they changed over the period from 1970 to the present?

From the point of view of historical geography the linkages between transportation and development would seem to be those of reciprocal cause and effect. For example, in the years before permanent European settlement of the Upper Midwest, Native Americans, explorers, and fur traders frequently used trails that followed water courses [2]. Trails connected the early settlements, which were later served by early railroad lines that branched out from pre-existing river and lake ports. The railroads reinforced previously advantageous geographical positions, and as lines were extended they both led and followed permanent agricultural, forestry, and mining settlements.

In the years just before and after World War I, the Federal-Aid-Secondary highway system of farm-to-market roads, which today form the backbone of Minnesota's state highway system, promoted agricultural development at the same time that it supported urban development. Farmers depended on towns and cities as markets for their produce, and urban centers depended on adjacent farm territories to provide customers for farm equipment, supplies and household needs. Meanwhile the Federal-Aid-Primary system of inter-urban roads, which today comprise the U.S. highway network, linked prominent urban centers and improved accessibility of places along the routes while bypassing other centers [3]. Well-served places flourished, while those that were by-passed often languished.

In the decades that followed Congressional passage of the Highway Act of 1956 authorizing the Interstate highway system, major metropolitan areas were connected with high-speed limited-access freeways without grade crossings. Fast-growing automobile-oriented suburban areas gained easy access to downtowns, downtown businesses dispersed to the suburbs, and large urban centers received circumferential routes that opened up vast exurban territories to development. From the point of view of historical geography, the relationship between highways and development seems to be one of circular and cumulative cause and effect. The goal of this report is to examine this relationship for the greater Twin Cities area during the period from 1970 to the 1990s.

Specific questions addressed in this report include the following:

- Do highway expansions or improvements at or near a place stimulate land development within that place?
- Does land development and associated activity in or near a place promote highway development to serve that place?
- Or is the relationship circular—as seems likely?
- Do statistical measures of lead-lag relationships remain constant through time?
- Do statistical measures of lead-lag relationships remain constant across locations?
- Do the statistical relationships differ depending on the type of development?

We report on our investigation of statistical relationships between highway transportation access (measured on a 13-point ordinal scale) enjoyed by each of 631 minor civil divisions in the 24 Minnesota and Wisconsin counties surrounding the Twin Cities of Minneapolis and St. Paul, and four types of land development (residential, commercial, industrial, office) as indicated by building-permit data reporting number of permits issued and value of new construction permitted for various time intervals from 1970 through the mid-1990s (Fig. 1.1).

We examined correlations between the timing of land development and transportation improvements for each of the four land development types and used simple regression models and maps of regression residuals to explore the processes in which development seems to follow as well as lead highway transportation improvements. Findings suggest that the impact of major highway improvements on land development patterns took one form in the 1970s, another in the 1980s, and still other forms in the 1990s. Findings also show how the relationships differ by development type.

To summarize, on the basis of the historical geography of settlement of the Upper Midwest and Minnesota, it seems evident that in many instances transportation improvements stimulated or led settlement and land development. The way that the Northern Pacific and Great Northern railroads opened up the northern Great Plains for agricultural settlement is a prominent example. Without the railroads it would have been impossible for successful agricultural settlement to

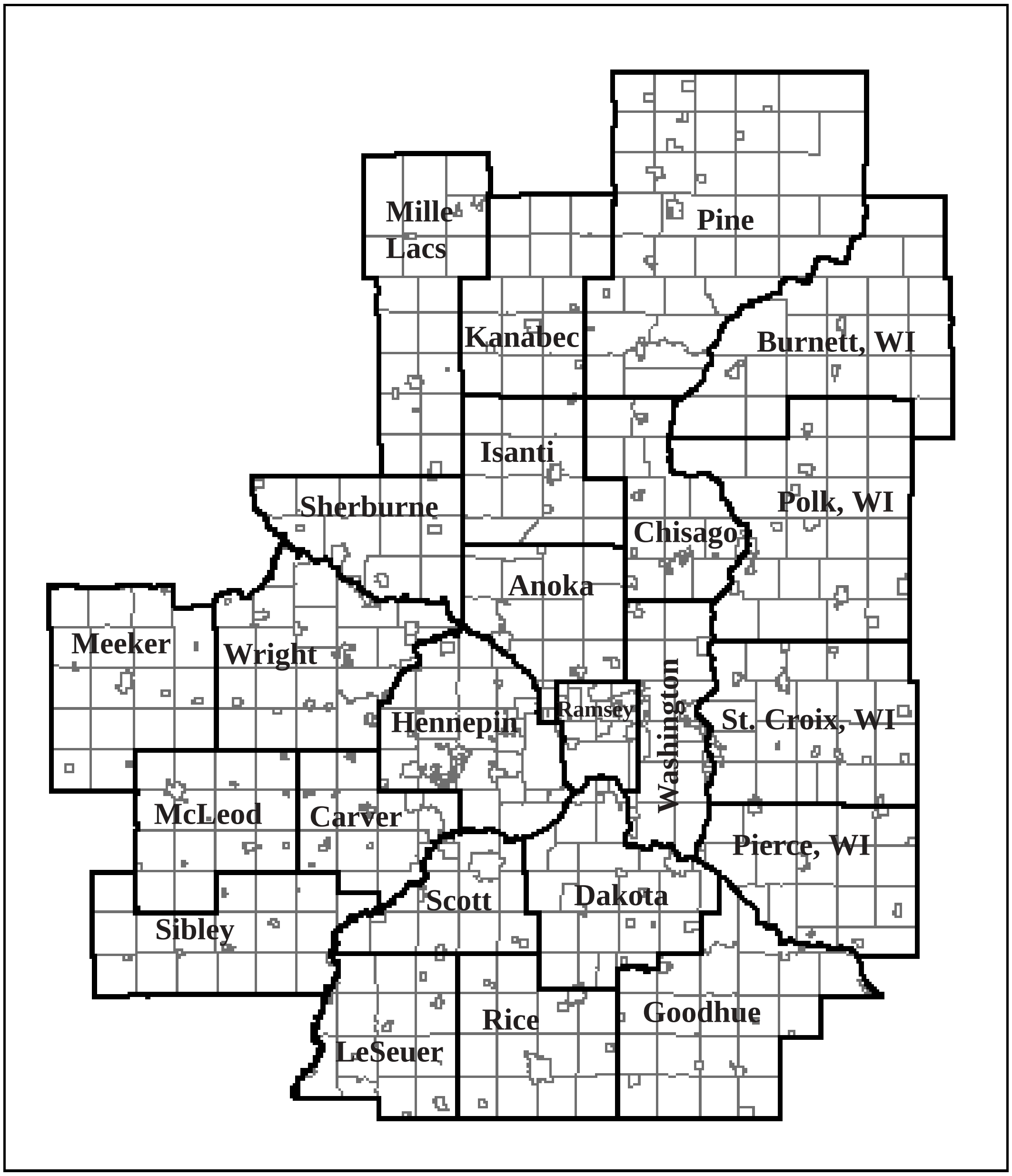


Figure 1.1 Minneapolis-St.Paul 24-County Study Area.
The 24 counties in Minnesota and Wisconsin are included in the statistical analysis of the relationship between highway accessibility and land development.

proceed at the scale that it did. On the other hand, Minnesota's iron mining industry provides examples of how the opening of mines on the Mesabi, Vermilion, and Cuyuna ranges led to the building of railroads to transport ore to the Lake Superior port at Duluth. Thus we approach the study of highway development in and around the greater Twin Cities region with the hypothesis that highway transportation and land development are circularly and causally related.

How We Examined Relationships over 24 Minnesota and Wisconsin Counties through Three Decades

We measured four types of development activity that were reported by permit-issuing cities, townships (MN) and towns (WI) in 24 Minnesota and Wisconsin counties for the years 1970–1997. The four types of development considered were housing, industrial, commercial, and office. The data on development came from reports assembled by the U.S. Department of Commerce. (See Appendix 1-A for a more detailed discussion of the data.) The Commerce Department series of building permit data relies on voluntary reports from permit-issuing places, and our use of these reports to estimate actual construction activity assumes that structures for which permits were issued were actually built, and that all or almost all of the important construction that occurred in the study area took place within jurisdictions that issued permits and reported them to the Commerce Department. We have no evidence that either of these assumptions is unwarranted. Our main interest in these data is to portray the volume and the geographical locations of construction during the study period in order to relate them to quality of highway accessibility and locations of highway improvements. Not all MCDs in the 24-county study area reported development activity or permits issued. Some MCDs reported zero permits issued; 217 of the 631 MCDs in the 24-county study area issued no reports at all for any of the time periods.

<u>Housing Construction Data</u>. The data on housing include housing starts by number of housing units and location. In this analysis we disregard the type of structure, such as single detached, single attached, duplex, apartment, and so forth. We consider only the number of separate housing units regardless of type of structure. We also disregard the market value of the individual units or the cost of construction.

<u>Industrial Construction Data</u>. Data on industrial development include its volume and location. Volume is assessed by the value of permits. This type of construction includes plants producing, processing, or assembling goods and materials, together with affiliated buildings such as warehouses, garages, administration buildings and so forth.

Commercial Construction Data. Commercial building permits are issued for stores and other mercantile buildings, which includes buildings used in buying, selling, distributing, or storing of merchandise and materials, or performing customer services such as stores, auto and other show rooms, commercial warehouses, grain elevators, garages for storing commercial vehicles, restaurants, taverns, bakery shops, laundry and dry cleaning shops, barber and beauty shops, animal hospitals, and similar facilities, including affiliated parking garages and administration buildings. Data on commercial development include volume and location. Volume is measured by the value of permits.

Office Construction Data. Office building permits are issued for office, bank, and professional buildings, but not office buildings affiliated with industrial buildings. Data on office construction, like that for industry and commercial development, include volume and location. Volume is measured by value of permits.

Data Standardization. The land development data as measured by permits granted by MCDs were standardized to take account of either the existing population density or the availability of vacant land at the beginning of the respective time period in the respective MCD. For example, standardized industrial permit value, 1990–94 is equal to the value of industrial permits granted in the years 1990–94, divided by vacant land per capita in 1990. Since we lack accurate measures of vacant land, we used the ratio of MCD area divided by MCD population as a surrogate for vacant land per capita. Thus, the data standardization was accomplished as follows:

- Housing construction permit data (housing units) were divided by “population density” of the MCD;
- Industrial permit value data (current dollars) were divided by “vacant land per capita” of the MCD;
- Commercial permit value data (current dollars) were divided by “population density” of the MCD;
- Office permit data (current dollars) were not standardized.

Five Growth Eras. The period 1970–1997 was subdivided into five growth eras: early 1970s (estimated using 1972 data, the only year from the early 1970s for which building permit data were available), late 1970s (estimated using 1979 data, the only year from the late 1970s for which data were available), 1980–84, 1985–89, and 1990–97 (some data series run only through 1994). This 28-year period could have been divided into fewer or more eras, but the data from the 1970s were too “lumpy” to permit further subdivision. Moreover, five years seemed like a reasonable time interval for any cause-effect relationships between highways and development to manifest themselves in ways that our data might reveal. Ten years seemed too long; two or three years seemed too short.

Highway Access. The data set also included scores for each minor civil division (MCD) in the 24 counties according to quality of the major highway facilities that served them at the end of each era. We assigned scores as follows (Table 1.1) [4].

Table 1.1: Transportation Scoring System

Score	**Meaning**
0	No arterials* within the MCD, and none in an adjacent MCD
1	No arterials within MCD, 1 multi-lane in an adjacent MCD
2	No arterials within, 1 limited-access highway in an adjacent MCD
3	No arterials within, 1 Interstate in an adjacent MCD
4	No arterials within, two or more adjacent OR any number of two lane arterials within
5	1 multi-lane within, no arterials in adjacent MCDs
6	1 limited-access within, no arterials in adjacent MCDs
7	1 Interstate within, no arterials in adjacent MCDs
8	1 multi-lane within, any number of arterials in adjacent MCDs
9	1 limited-access within, any number of arterials in adjacent MCDs
10	1 Interstate within, any number of arterials in adjacent MCDs
11	2 or more multi-lanes within, any number of arterials in adjacent MCDs
12	Any combination of multi-lane and limited-access/Interstates OR two or more limited-access/Interstates within, any number of arterials in adjacent MCDs

* Arterials include multi-lane, limited-access, or Interstate highways categorized as Principal Arterials under the Functional Classification system of the Minnesota Department of Transportation. Two-lane arterials are considered only if they are the only Principal Arterials present within an MCD (such MCDs receive a score of 4) [5].

The lowest score of zero indicates the lowest level of access—that is, no direct, convenient access to the system of metropolitan arterials. Since a city or township can still have access to a major arterial if that arterial is in the neighboring MCD, this scoring system starts with all such possibilities (scores of 1–4). Multi-lane highways are understood to provide less access than limited-access roads, which provide less access than Interstate highways [6]. Two-lane arterials are not likely to strongly influence development, and thus are counted if that is the only type of major road within an MCD.

Next higher in rank are places with one major arterial of their own, but none in neighboring cities or townships (scores of 5–7). Scores of 8–10 refer to places with a major arterial within their borders and one or more major arterials in an adjacent city or township. The highest scores (11–12) are achieved by those places containing more than one major arterial, with any number in adjacent MCDs. Initial scores were calculated from the 1970 official state highway maps of Minnesota and Wisconsin, and subsequent changes were made as noted on the same maps for 1979/80, 1985/86, 1989/90, and 1997/98. (See Appendix 1-A for a more detailed discussion of the data.)

MCD Location. Each MCD was ranked from 1 to 19 according to its location relative to its distance from the core of the Minneapolis-St. Paul urbanized area (Fig.1.2). The first seven ranks come from the Metropolitan Council's land development control classification system, which applies to its seven-county jurisdiction (Hennepin, Ramsey, Washington, Anoka, Carver, Scott, and Dakota Counties) (Table 1.2)

Statistical Methods for Relating MCD Development to Highway Transportation Scores

There are 631 MCDs in our 24-county study area. The number of reporting places varied from 259 in 1979 for residential, industrial and commercial development to 414 in the 1980s for residential development. Data standardization yielded for each reporting MCD an index number that considers either the existing population density of an MCD or the availability of vacant land in an MCD.

Step 1: Scatter Plots. Because we were faced with a large volume of data (transportation scores and building permit data for five different time periods for 631 MCDs), our statistical analysis begins with a scatterplot matrix of transportation versus development. Each scatterplot matrix displays separate plots for each possible pairing of variables (each possible pairing of time periods). Therefore, for our exploration of the association between transportation and residential development, the scatterplot matrix contains a plot of transportation for each of five time periods vs. rates of new residential development for each of five time periods (25 plots in all).

Scatterplots provide a useful visual method of exploratory data analysis. Each scatterplot portrays the degree and nature of a statistical relationship between two variables: whether there is a positive or negative direction of correlation; whether the assumption of a linear relationship between the variables appears to be appropriate; and how strong the relationship appears to be. We include the best fitting lines (using ordinary least squares regression) on each of the scatterplots in the matrix. The slope of the best fitting line suggests the extent to which the quality of

Table 1.2. Location Variable.

Location*	Definition	Description
1	Urban Core	Cities of Minneapolis and St. Paul
2	Urban Area	Built-up area, bounded by the 2000 Metropolitan Urban Service Area (MUSA)
3	Illustrative 2020 MUSA	Zone specified for staged expansion of the 2000 MUSA
4	Urban Reserve	Land reserved to accommodate growth to 2040
5	Rural Growth Centers	Small rural-area cities with central sewer service
6	Permanent Agricultural Area	Protected from urbanization; no more than one dwelling per 40 acres
7	Permanent Rural Area	Mix of farm and non-farm uses; protected from urbanization; no more than one dwelling per 10 acres
8	0 to 6 miles	Measured from edge of 7-county metro core
9	6 to 12 miles	
10	12 to 18 miles	
11	18 to 24 miles	
12	24 to 30 miles	
13	30 to 36 miles	
14	36 to 42 miles	
15	42 to 48 miles	
16	48 to 54 miles	
17	54 to 60 miles	
18	60 to 66 miles	
19	66 to 72 miles	

*Location Variables 1 through 7 are based on the Metropolitan Council's Metro 2040 map of planned land uses, part of its Regional Blueprint. Location Variables 8 through 19 are measured as distance beyond the seven-county border.

Data Source: Metropolitan Council, Metro 2040: A Growth Strategy for the Twin Cities Metropolitan Area. St. Paul MN: Metropolitan Council. April 1997. Calculations by authors.

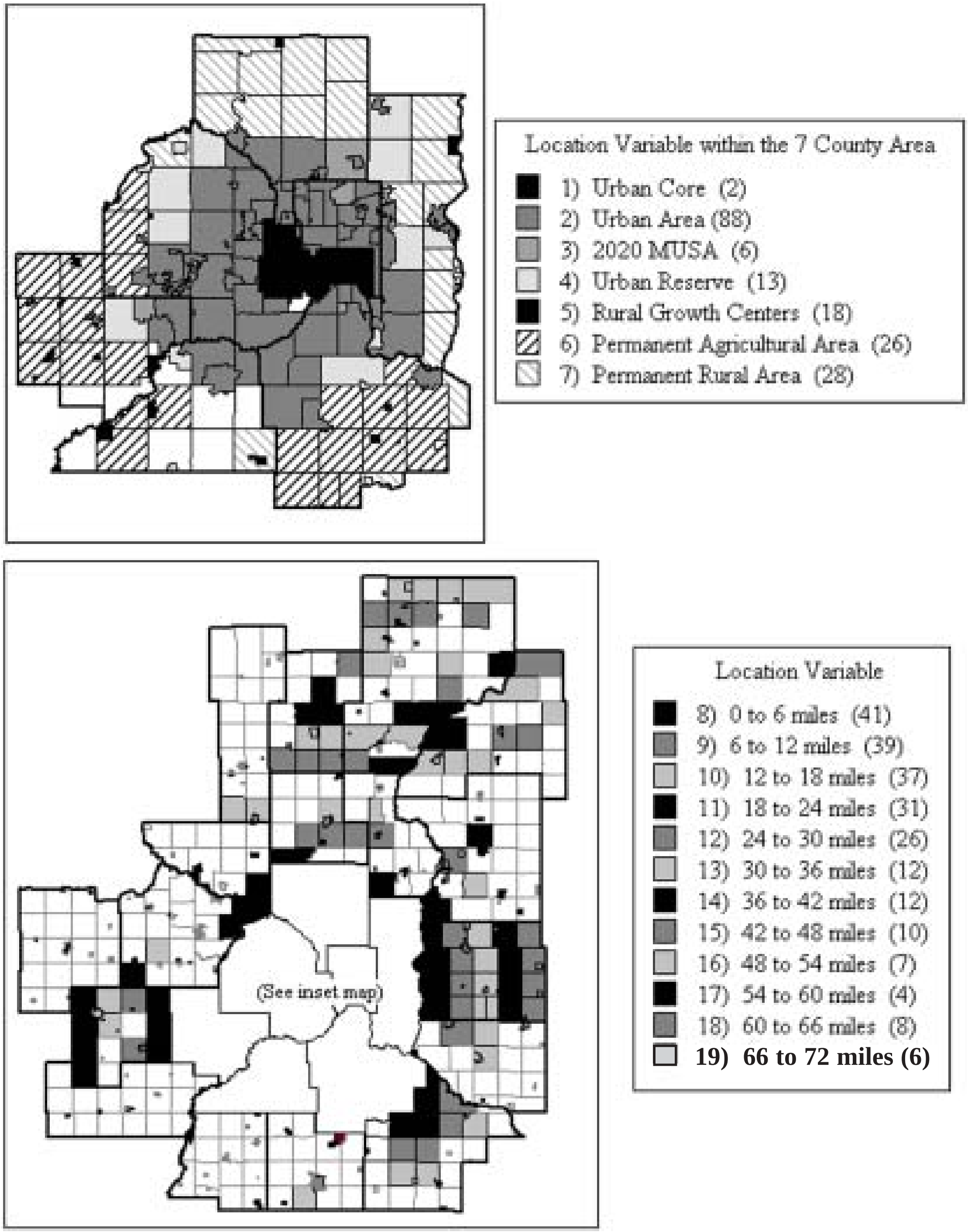


Figure 1.2
Location Variable for the 24-county Area.

local highway transportation facilities leads real estate development in the same or in another time period. The scattering of points away from the best fitting line reveals the strength of the association, while also portraying outlying MCDs that for unspecified reasons depart significantly from the trend followed by other MCDs.

Step 2: Correlation Analysis. The scatterplots are the first step in the correlation analysis. The second step is the calculation of correlation coefficients, which provide a quantitative measure of the association or co-variation between a pair of variables. However, correlation analysis does not imply a cause-and-effect relationship; it merely measures the degree of association between two variables. In our analysis, we assume a linear relationship between the quality of highway transportation facilities serving an MCD and land development within the MCD, and employ a widely used measure of statistical association, Pearson's correlation coefficient r. These coefficients vary between the minimum possible value of -1.0, which indicates perfect inverse correlation, and the maximum possible value of +1.0, which indicates perfect positive correlation. A value of 0.0 indicates no correlation or statistical association between the two variables. For each section below, we present the correlation coefficients for all of the scatterplots in the matrices.

Some notes of caution are necessary in interpreting the results of our preliminary correlation analysis. First of all, it is possible that different geographical scales of analysis would yield different degrees of correlation. We used data for local units of governments (MCDs), but the results of the calculations might have been different had we used data at the county scale, or from census tracts or block groups. By analyzing relationships at the MCD scale, we assume that highway access at any location within the MCD will be relevant for housing and for other real estate development at any other location within the MCD. This assumption will not apply uniformly across our study area because of varying shapes and sizes of MCDs in the 24 counties. However, throughout this study we treat municipal and township governments as active agents in the development process, so we concluded that statistical analysis at the MCD level is the most feasible and appropriate. A second caution is that this initial correlation analysis is highly simplified. We consider only a few of the many variables that govern land development activity.

We assume a linear relationship between transportation and development based on our hypothesis that increased transportation access will lead to increased development (and vice versa) and on the scatterplots of transportation versus each type of development. But we recognize that there exists non-constant variance in the plots of residuals from our regression analysis; that is, variability in the sizes of the residuals rises as MCD highway transportation scores increase.

This variation occurs because of the wide range of development data values. For example, many places have no office development even though they have a high transportation score, while other places with similar transportation scores have millions of dollars of office development. These large values of development have more “room” to vary than do small values, and they generally occur with higher values on the x-axis (MCD highway transportation scores). However, this non-constant variance does not suggest that development is a nonlinear function of transportation.

Step 3: Linear Regression. In each section, our statistical analysis of the relationship between MCD transportation scores and levels of land development continues with a closer examination of the scatterplot and regression line for the different time periods. By displaying the regression line in this way (with transportation scores on the horizontal x-axis, and measures of land development on the vertical y-axis), we imply that transportation is the independent variable, and that variations in highway transportation services account for variations in the dependent variables, that is, the levels of various types of real estate development. The volume of each type of incremental land development is affected by the quality of highway transportation infrastructure that serves the MCD that contains it. The slope of the regression line indicates the level of change in development activity associated with a change in highway transportation score.

Transportation in turn is affected by each type of development. Scatterplot matrices with highway transportation scores as the response and levels of new development put in place as the independent predictor revealed a need for more detailed analysis, such as multiple regression. Further complicating a multiple regression analysis is the high degree of correlation between the development variables themselves. Here, we examine in a preliminary way the influence of highway transportation on each type of development, using only a single-variable model.

The next analytical step is a presentation of informative statistics from the regression analysis [7]. Five different regression analyses were performed in each section, one for each of the five scatterplots along the diagonal of the scatterplot matrix (those plots showing relationships between transportation and development during the same time period, i.e., 1972, 1979, 1980–84, 1985–89, and 1990–94 or 1990–97). In a regression analysis, the value of the coefficient of determination (r^2) measures the ability of the independent variable (MCD highway transportaltion score) to account for variation in the dependent variable (volume of land development). This coefficient ranges from 0.0 to 1.0, and can be interpreted as the percentage of the variation in development experienced by MCDs that is explained by variation in the transportation score. Finally, the F-statistic is used to evaluate the significance of the r^2 value. Using this test, we concluded in almost every regression analysis that we ran that variations in highway transportation infrastructure serving MCDs account for a statistically significant amount of the variation in real estate development within MCDs [8].

Step 4: Residuals from Regression. The deviation of each plotted observation from the expected trend (the regression line) is termed a "**residual from regression**." We performed residual analysis on the major outliers (the large development values that usually occur with larger transportation scores), and determined that the "**leverage values**" for these points are not statistically significant. That result means that we can safely conclude that these prominent outliers are not having a noticeably disproportionate influence on the fit or the slope of the regression lines.

We also investigated the geographical patterning of the major outliers from the expected trends for the relationships between transportation scores and development levels (as determined by the regression analysis). In each chapter following, we map and discuss the twenty largest outliers from our expected trends for each time period [9].

Step 5: Transformation of the Development Variable. For each type of development, in any one development era, a few MCDs report large numbers or values of permits issued, while most report issuing no permits, or much smaller numbers or values of permits. The distribution of permits issued by MCDs is highly skewed, with a disproportionate number of observations of zero. This results in the statistical problem of nonconstant variance, where variance in the amount of development increases as transportation scores increase. One solution to this problem is to transform the development variable with a variance stabilizing transformation, such as a square root or logarithmic transformation. Such a transformation allows us to better assume a linear relationship between development and transportation. A transformation is performed and explained in each section, and the resulting correlation coefficients between the transformed development variable and transportation are presented and discussed.

Step 6: Multiple Regression. The final step in our statistical analysis is the addition of the location variable to our regression model [10]. Just as was done for the simple regression model, informative statistics from the multiple regression analysis are presented for each of the five scatterplots along the diagonal of the scatterplot matrix (those plots showing relationships between transportation and development during the same time period). In this case, the coefficient of determination (r^2) measures the ability of both transportation and location together to account for variation in the transformed development variable. Using the F-test, we concluded in every regression analysis that we ran that the transportation and location variables together account for a statistically significant amount of the variation in real estate development [11].

We collected data on changes to these Principal Arterials (based on the categories of two-lane highways, multiple-lane highways, limited-access freeways, and Interstates) using Minnesota and Wisconsin Official State Highway Maps. These maps were compared across the years of 1970, 1979/80, 1985/86, 1989/90, 1997/98 to determine any new construction of arterials or upgrades to existing arterials.

Endnotes

1. For example: Borchert, John R. "American Metropolitan Evolution." *Geographical Review* 57:3 (1967) 301-32; Forkenbrock, David J. and Norman S. J. Foster. "Economic Benefits of a Corridor Highway Investment." *Transportation Research* A 24A:4 (1990) 302-12; Giuliano, Genevieve. "The Weakening Transportation-Land Use Connection—It Still Eludes Us." *ACCESS*, Spring 1995; Rephann, Terence and Andrew Isserman. "New Highways As Economic Development Tools: An Evaluation using Quasi-Experimental Matching Methods." *Regional Science and Urban Economics* 24:6 (1994) 723-51; Singletary, Loretta, Mark Henry, Kerry Brooks, and James London. "The Impact of Highway Investment on New Manufacturing Employment in South Carolina: A Small-Region Spatial Analysis." *The Review of Regional Studies* 25:1 (1995) 37-55; and Stephanedes, Yorgos J. and David Eagle. "Highway Impacts on Regional Employment." *Journal of Advanced Transportation* 21: Spring (1987) 67-79.

2. Borchert, John R. and Donald P. Yaeger. "The Transportation Network." Ch. 9 in *Atlas of Minnesota Resources and Settlement*. Minneapolis: University of Minnesota, Department of Geography, 1968. pp. 132-62.

3. U.S. Department of Commerce, Bureau of the Census. "Transportation-Land." in *Statistical Abstract of the United States: 1993* (113th Edition). Washington, DC: 1993. pp. 607-8, and Tables 1009, 1010, 1014.

4. In our opinion, the differences in the results of the analysis using one ordinal ranking system rather than another are trivial. For a discussion of the power and the information content of ordinal ranking systems, see Adams, J.S., Abler, R.F., and Gould, P.R. 1971. "The problem of measurement and scaling," Chapter 4 in *Spatial Organization. The Geographer's View of the World*. Englewood Cliffs, N.J.: Prentice-Hall, pp. 93-110.

5. Some operational decisions were needed to apply these rules:

- A limited-access or Interstate highway counts only if it has an exit within that MCD, or one clearly meant to serve that MCD.
- If an MCD contains a multi-lane road that becomes an Interstate highway in the adjacent MCD, the first MCD is considered to have an Interstate exit (for example, Faribault in 1970).

- Adjacency did not count if the MCDs in question were separated by a river with no bridge between them. Distance between adjacent MCDs (or within an MCD) is not considered by this scoring system.
- Forks count as two separate roads-for example, I-35E and I-35W in Lino Lakes Township are considered two different arterials.

6. This assumption may not always prove true, however. For example, the conversion of Highway 12 to Interstate 394 in the 1990s added nothing other than a High-Occupancy Vehicle (HOV) lane. In fact, until the recent restriping/overlay reconverted the road to six lanes for single-occupant vehicles, the old multi-lane highway provided more capacity for single-occupant vehicles than did the new Interstate.

7. The values of the y-intercept (constant *a*) and the slope (*b*) for each line are not presented here because they are not useful to our analysis. The y-intercept represents the amount of real estate development of a particular type that an MCD should have with zero transportation access. However, our definition of an MCD with a score of zero does not mean that the place has absolutely no transportation access. In many cases, the best fitting line has an intercept indicating a negative value of development, which is obviously not meaningful. The slope of the line reveals how responsive development is to a change in transportation access; however, the magnitude of the slope is affected by the units of measurement (here, we use both number of units and value of permits), and thus cannot be used as a valid index of the relative relationship between two variables.

8. The p-value of the F-statistic for every regression analysis was 0.0, except for residential development in 1990–97 (p-value = 0.42) and commercial development in 1979 (p-value = 0.10).

9. As measured by their Studentized Residuals—residuals that have been scaled to relate the magnitude of each residual to the size of the typical residual (or standard error). This procedure is followed to avoid problems with large values for residuals measured in absolute terms.

10. Because there is not a true ranking to the 19 different location categories (Location 6 (Permanent Agricultural Area) is not necessarily a “higher” or “lower” rank than Location 7 (Permanent Rural Area), the Location variable is considered to be categorical data. Thus it is included in the regression model as dummy variables, rather than as an additional independent variable.

11. The p-value of the F-statistic for every regression analysis was 0.0.

12. Metropolitan Council. 1996. *Transportation Policy Plan, Twin Cities Metropolitan Area*, Pub. No. 35-97-010. St. Paul, MN: Metropolitan Council, p.100.

Chapter 2

Residential Development and Transportation

Residential Development and Transportation: Hypothesized Linkages

We expected the relationship between highway availability and highway improvements, on the one hand, and residential development, on the other, to be one of mutual cause and effect. Highways that serve vacant land close to the built-up metropolitan core make those areas convenient for new residential development. At the same time, the development and occupation of new residential areas (whether previously served by major transportation routes or not) generate demand for improved or expanded highway transportation infrastructure.

Housing permit data for each MCD that reported data were standardized by dividing the number of units permitted by population density within the MCD (Table 2.1). For example, an MCD with a population density of 1,000 persons per square mile and issuing permits for 400 new housing units would have an index number of 0.4 (i.e., 400/1,000). The greater the existing population density in an MCD, the smaller the index number. If during a certain time period a substantial volume of new housing construction is of the fill-in variety and concentrates in MCDs that have already high population densities, the average index number will be small. On the other hand, if new housing in another time period is built primarily in newly developing MCDs that have low population densities, the index number will be large. The mean and median values of the index generally get larger in more recent periods, implying that in the 1990s there was a tendency for new housing to be built in low-density areas compared with the fill-in variety. Although the average index numbers have been rising, the standard deviation of values in the 1990s is substantially higher than in earlier time periods, implying that recently there is more variety in residential development patterns than was the case in earlier periods.

The data set provides for each MCD a transportation score (0–12), and a standardized number of housing units permitted, for each of the five time periods. When MCDs are plotted according to their transportation scores in each time period, and standardized number of housing units in each time period, the result is an array of scatterplots on a 5-by-5 matrix (Fig. 2.1). The five scatterplots on the diagonal from lower left to upper right portray how MCD transportation scores are related to residential construction at approximately the same time the construction was taking place. Scatterplots to the right and below the diagonal portray transportation scores for time periods following housing construction. Scatterplots to the left and above the diagonal

Table 2.1. Descriptive Statistics for the Data on Standardized Number of Residential Units, by Time Period, 1972 to 1997.

Time Period	Number of Cases	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation
1990-97	413	57	0.2	1.4	4	3
1985-89	414	9	0.0	0.5	1	2
1980-84	414	6	0.1	0.4	1	2
1979	259	15	0.0	0.3	1	3
1972	328	28	0.0	0.4	2	5

Standardized Number of Residential Units is defined as MCD number of residential units divided by MCD population density (population per square mile).
Data Source: U. S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

Table 2.2. Correlation Values of the Relationship between Transportation and Standardized Number of Residential Units, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
	1990-97	0.04	0.04	0.04	0.03	*0.04*
	1985-89	0.34	0.35	0.37	*0.36*	0.37
Residential	1980-84	0.35	0.36	*0.38*	0.38	0.39
	1979	0.20	*0.19*	0.24	0.24	0.24
	1972	*0.14*	0.14	0.19	0.19	0.19

Values are Pearson's correlation coefficients, *r*.
Data Source: Calculations by authors.

Table 2.3. Coefficient of Determination Values (r^2) from Regression Analysis of the Relationship between Transportation and Standardized Number of Residential Units, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
	1990-97					0.00
	1985-89				0.13	
Residential	1980-84			0.15		
	1979		0.04			
	1972	0.02				

The p-value for each regression's F-statistic < 0.01, except for 1990-97 with a p-value 0.42.
Data Source: Calculations by authors.

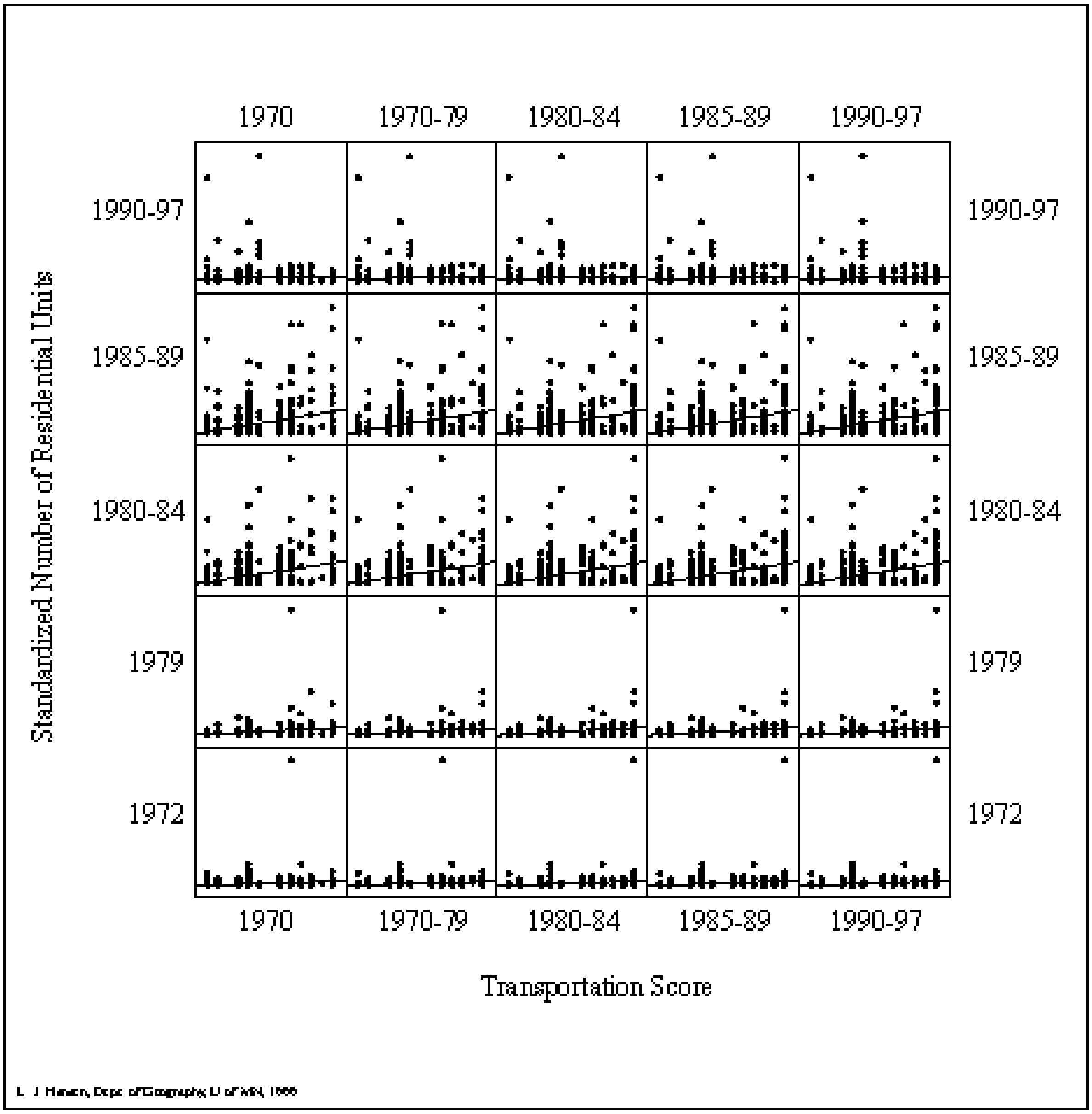


Figure 2.1. Scatterplot Matrix Showing Relationship between Transportation and Standardized Number of Residential Units, by Time Period, 1970–1997.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

describe for MCDs how transportation scores in an earlier time period are related to construction in later periods.

What Do the Data Show?

A matrix of 25 correlation values for the 5-by-5 array of scatterplots discloses little correlation between transportation scores and housing construction in the early 1970s ($r = 0.14$) (Table 2.2). But by the late 1970s, the correlation had climbed to 0.19, then reached 0.38 and 0.36 in the 1980s before dropping to 0.04 in the 1990s. These simple statistics imply that residential growth on the edge of the built-up area in the early 1970s bore little relationship to the location of major highways, but by the 1980s the full effects of the recently-completed Interstate system and the upgrading of other major arterials was being strongly felt. Correlation coefficients for the 1980s imply that places well served by major highways were receiving disproportionate shares of the new construction given their population densities. By the 1990s, the low correlation (0.04) implies that because most places in the 24-county region are by now well served by major highways, the locational patterns of new construction must be explained by variables other than by highway transportation scores. The coefficients of determination (r^2) from simple regressions relating residential development as a function of highway transportation score for each of the five time periods inform us that even though correlations peaked in the 1980s, variations in transportation scores account for only about one-seventh of the variation from MCD to MCD in the volume of new housing permits issued (Table 2.3). The rest of the variation must be due to attributes of MCDs other than the quality and quantity of arterial highways serving them.

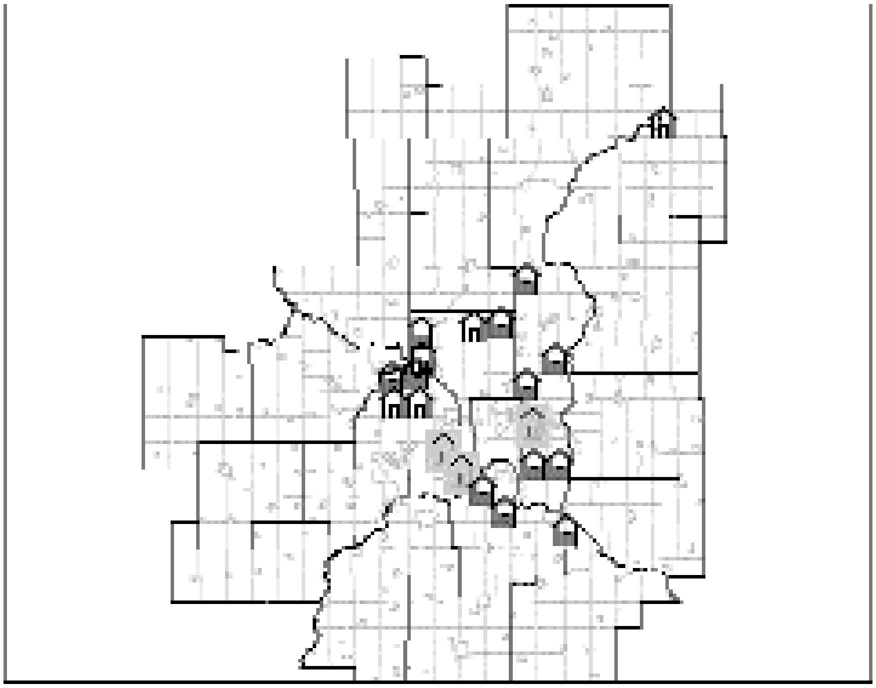
Residual Unexplained Variations in Housing Construction Permits

“**Transportation scores**” report how well MCDs are served by high-capacity, high-speed highways. “**Standardized residential units**” report new construction authorized, weighted by MCD population density. A certain amount of the variation in housing construction among MCDs is accounted for by transportation scores and population density, but most of the unexplained or “residual” variation is evidently due to additional MCD features. This residual unexplained variation can be allocated to MCDs using the regression model to calculate (1) the number of standardized residential units that might have been expected to be built given an MCD’s transportation score (i.e., predicted units) and comparing this prediction with (2) the standardized number of units actually built. This procedure allows us to ascertain which MCDs were over-predicted (i.e., fewer units built than expected) and those that were under-predicted (i.e., more units built than expected).

For example, in the early 1970s, the city of Eagan (with a transportation score of 8) had a predicted index of standardized residential units of 0.61, but an actual index of 28.18 (Fig. 2.2). In other words, Eagan experienced vastly more residential construction than predicted based solely on its transportation score and population density. Other MCDs with substantially more housing construction than predicted form a band around the solidly built-up metro core, while those that were significantly over-predicted include fully built-up cities like Richfield and St. Louis Park, namely cities that were well served by high-quality highways in the early 1970s but had little or no new residential construction. This map of regression residuals implies that the location of an MCD with respect to the location of the built-up margins of the urbanized area explains some of the levels of construction activity that are not accounted for by highway scores and population density.

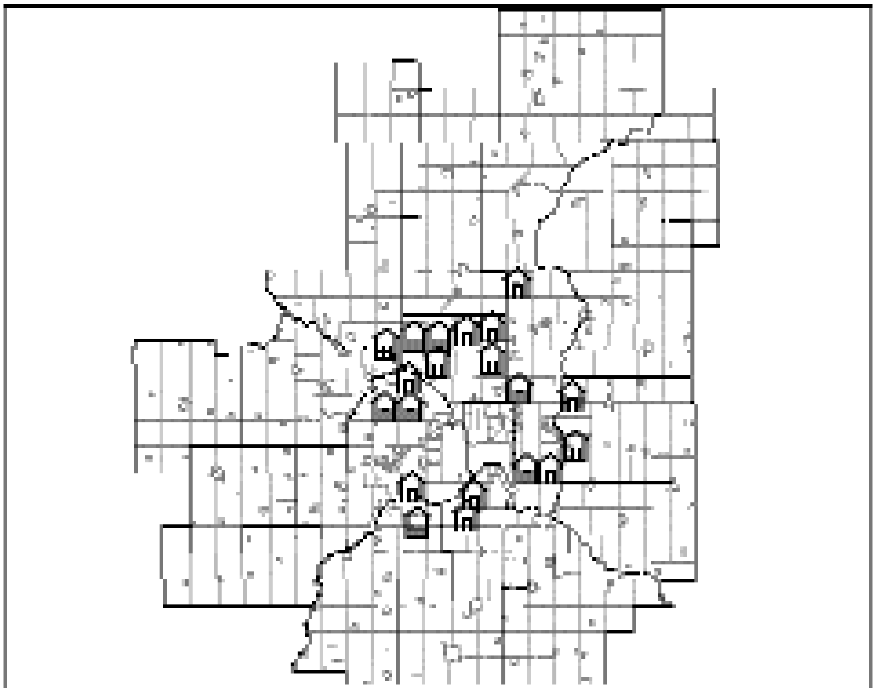
The map of residuals for the late 1970s again reveals a band of MCDs that received significantly more housing than predicted by the regression model based on transportation scores and population density (Fig. 2.3). The city of Eagan was still receiving substantially more housing than predicted, along with several of the northern suburbs plus Hudson town and Somerset town east of the St. Croix River in Wisconsin. By the early 1980s, the large positive residuals indicating more new housing than predicted are at two main locations: the second- and third-ring suburbs around the Twin Cities, plus widely scattered outliers (Fig. 2.4). In the late 1980s, the geographical distribution of the large positive residuals of the early 1980s repeats, but in suburbs still farther out, and with additional outliers in northern Anoka County, Wright County, and St. Croix County (WI) (Fig. 2.5).

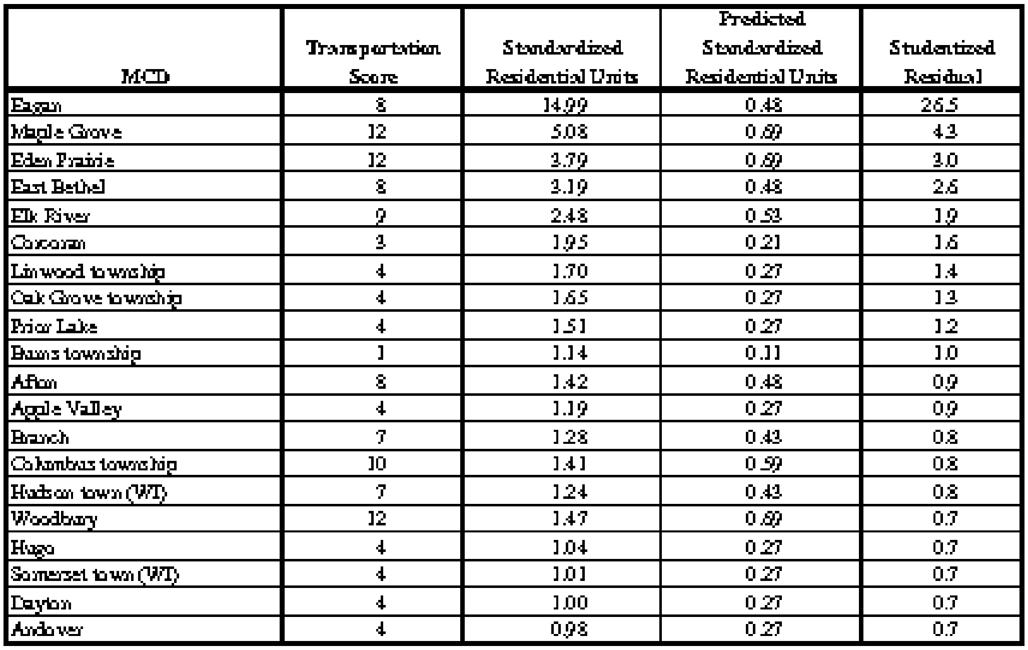
In the 1990s, the largest positive residuals are for MCDs scattered throughout the study area, suggesting that the roles of highway scores and population density have essentially disappeared compared with other features and events as explanations for the variations among MCDs in the volume of new housing construction (Fig. 2.6). Recall that the coefficient of determination (r^2) for the 1990–97 regression of the relationship between transportation and standardized number of residential units was 0.0 (Table 2.3). Thus, we can conclude that by the 1990s, when high-quality highways served most parts of the 24-county study area, and vast quantities of developable land were available in areas both inside and outside the Metropolitan Council's seven-county jurisdiction, conditions within individual MCDs—as expanding employment centers, or especially attractive natural amenities, or decisions by an especially large and aggressive development company, or any of a number of other local features—could lead to a greater than expected volume of new housing construction.



MCD	Transportation Score	Standardized Residential Units	Predicted Standardized Residential Units	Studentized Residual
Eagan	8	28.18	0.61	47.2
Dayton	4	4.70	0.34	2.7
Ramsey	9	4.72	0.67	2.5
Hugo	4	3.44	0.34	1.9
Swiss town (WI)	0	2.66	0.07	1.6
Woodbury	12	3.08	0.87	1.4
Ravenna township	4	2.21	0.34	1.1
Hassan township	0	1.68	0.07	1.0
Linwood township	4	1.90	0.34	1.0
Maple Grove	10	2.19	0.74	0.9
East Bethel	8	2.00	0.61	0.8
Branch	7	1.86	0.54	0.8
Burns township	1	1.38	0.14	0.8
New Scandia township	3	1.38	0.27	0.7
Corcoran	3	1.32	0.27	0.6
Rosemount	8	1.64	0.61	0.6
Afton	8	1.62	0.61	0.6
Pine Springs	12	0.00	0.87	(0.5)
Richfield	12	0.00	0.87	(0.5)
St. Louis Park	12	0.01	0.87	(0.5)

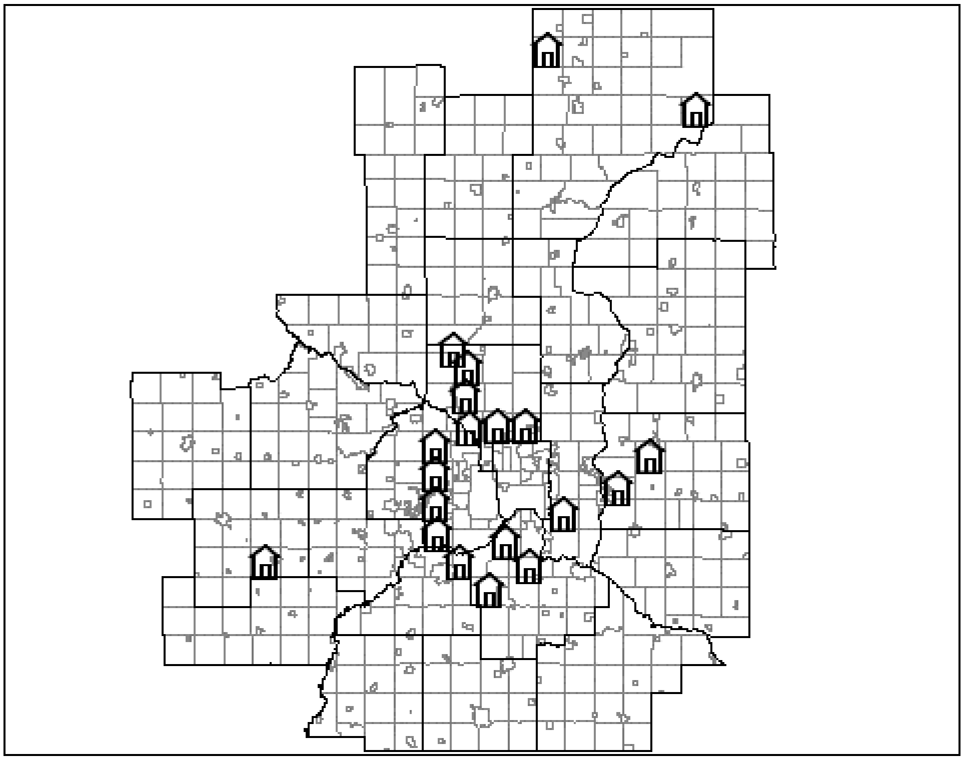
Figure 2.2. Top Twenty Outliers, Standardized Residential Units vs. Transportation, 1990–97.
Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

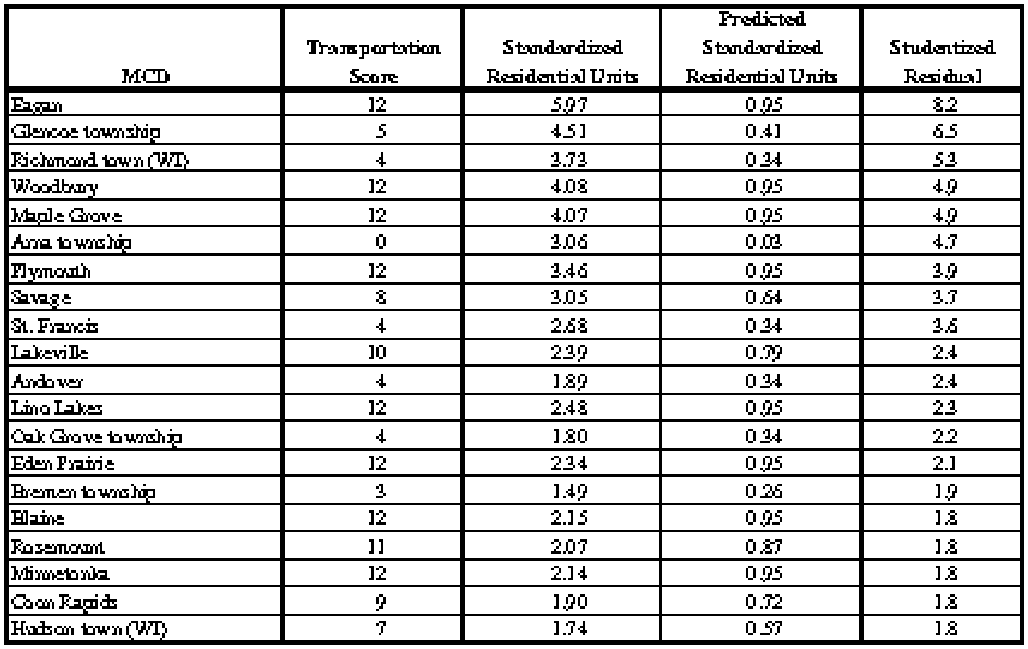




MCD	Transportation Score	Standardized Residential Units	Predicted Standardized Residential Units	Studentized Residual
Eagan	8	14.99	0.48	26.5
Maple Grove	12	5.08	0.69	4.3
Eden Prairie	12	3.79	0.69	3.0
East Bethel	8	3.19	0.48	2.6
Elk River	9	2.48	0.53	1.9
Corcoran	3	1.95	0.21	1.6
Linwood township	4	1.70	0.27	1.4
Oak Grove township	4	1.65	0.27	1.3
Prior Lake	4	1.51	0.27	1.2
Burns township	1	1.14	0.11	1.0
Afton	8	1.42	0.48	0.9
Apple Valley	4	1.19	0.27	0.9
Branch	7	1.28	0.43	0.8
Columbus township	10	1.41	0.59	0.8
Hudson town (WI)	7	1.24	0.43	0.8
Woodbury	12	1.47	0.69	0.7
Hugo	4	1.04	0.27	0.7
Somerset town (WI)	4	1.01	0.27	0.7
Dayton	4	1.00	0.27	0.7
Andover	4	0.98	0.27	0.7

Figure 2.3. Top Twenty Outliers, Standardized Residential Units vs. Transportation, 1979. Negative outliers shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



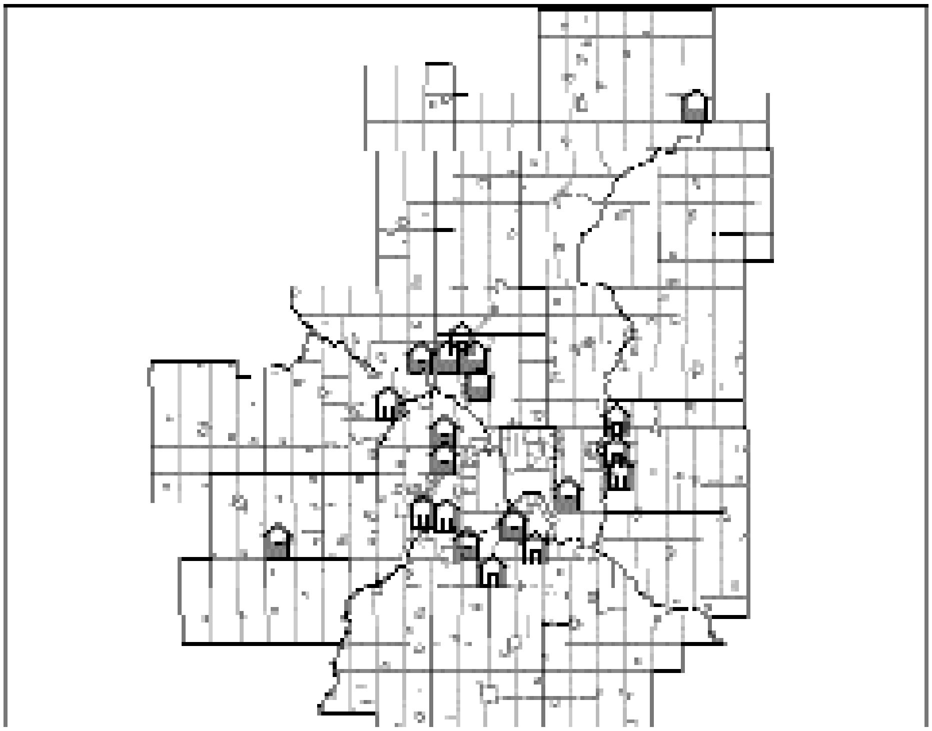


MCD	Transportation Score	Standardized Residential Units	Predicted Standardized Residential Units	Studentized Residual
Eagan	12	5.97	0.95	8.2
Glencoe township	5	4.51	0.41	6.5
Richmond town (WI)	4	3.73	0.34	5.3
Woodbury	12	4.08	0.95	4.9
Maple Grove	12	4.07	0.95	4.9
Ama township	0	3.06	0.03	4.7
Plymouth	12	3.46	0.95	3.9
Savage	8	3.05	0.64	3.7
St. Francis	4	2.68	0.34	3.6
Lakeville	10	2.39	0.79	2.4
Andover	4	1.89	0.34	2.4
Lino Lakes	12	2.48	0.95	2.3
Oak Grove township	4	1.80	0.34	2.2
Eden Prairie	12	2.34	0.95	2.1
Bremen township	3	1.49	0.26	1.9
Blaine	12	2.15	0.95	1.8
Rosemount	11	2.07	0.87	1.8
Minnetonka	12	2.14	0.95	1.8
Coon Rapids	9	1.90	0.72	1.8
Hudson town (WI)	7	1.74	0.57	1.8

Figure 2.4. Top Twenty Outliers, Standardized Residential Units vs. Transportation, 1980–84.

Negative outliers shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

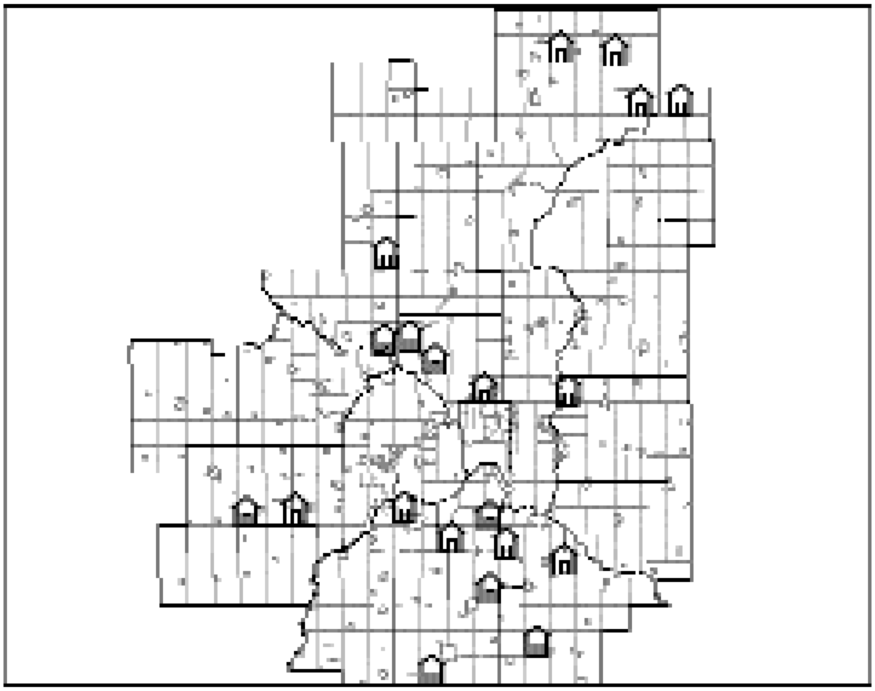


MCD	Transportation Score	Standardized Residential Units	Predicted Standardized Residential Units	Studentized Residual
Eden Prairie	12	8.87	1.44	7.1
Ama township	0	6.63	0.02	6.2
Elk River	9	7.67	1.09	6.2
Eagan	12	7.68	1.44	5.9
Woodbury	12	7.37	1.44	5.6
Andover	4	5.04	0.50	4.2
Lakeville	10	5.51	1.20	4.0
Glencoe township	5	4.82	0.61	3.9
Chanhassen	8	4.64	0.97	3.4
Savage	8	4.37	0.97	3.1
Plymouth	12	4.58	1.44	2.9
St. Francis	4	3.53	0.50	2.8
Maple Grove	12	4.40	1.44	2.7
Burns township	1	2.90	0.14	2.5
Hudson town (WI)	7	3.28	0.85	2.2
Somerset town (WI)	4	2.84	0.50	2.1
Oak Grove township	4	2.84	0.50	2.1
Frankfort township	7	3.14	0.85	2.1
Rosemount	11	3.55	1.32	2.0
St. Joseph town (WI)	4	2.70	0.50	2.0

Figure 2.5. Top Twenty Outliers, Standardized Residential Units vs. Transportation, 1985–89.

Negative outliers shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Standardized Residential Units	Predicted Standardized Residential Units	Studentized Residual
Wanamingo township	5	56.60	1.47	16.1
Blaine town (WI)	0	47.30	1.24	12.4
Welch township	5	29.99	1.47	6.1
Sciota township	1	18.87	1.28	4.1
Vermillion township	5	17.78	1.47	3.8
Young America township	5	14.79	1.47	3.1
Hassan township	3	13.24	1.38	2.7
Glencoe township	5	11.96	1.47	2.4
Ana township	0	10.08	1.24	2.0
Rosemount	11	7.38	1.76	1.3
Andover	4	6.93	1.43	1.3
Lakeville	10	6.96	1.71	1.2
Elk River	9	6.81	1.67	1.2
Park township	0	6.32	1.24	1.2
Lino Lakes	12	6.27	1.81	1.0
Princeton township	5	5.74	1.47	1.0
Somerset town (WI)	4	5.62	1.43	1.0
Warsaw township	7	5.59	1.57	0.9
Shakopee	8	5.60	1.62	0.9
Burns township	1	5.11	1.28	0.9

Figure 2.6. Top Twenty Outliers, Standardized Residential Units vs. Transportation, 1990–97.

Negative outliers shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

Table 2.4. Correlation Values of the Relationship between Transportation and LOG of Standardized Number of Residential Units, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Residential	1990-97	0.15	0.16	0.17	0.16	*0.17*
	1985-89	0.38	0.40	0.42	*0.41*	0.42
	1980-84	0.39	0.40	*0.42*	0.42	0.43
	1979	0.30	*0.29*	0.33	0.33	0.33
	1972	*0.29*	0.29	0.31	0.31	0.32

Values are Pearson's correlation coefficients, *r*.
Data Source: Calculations by authors.

Table 2.5. Coefficient of Determination Values (r^2) from Multiple Regression Analysis of the Relationship of Transportation and Location to LOG of Standardized Number of Residential Units, by Time Period, 1970 to 1997.

		Transportation and Location				
		1970	1970-79	1980-84	1985-89	1990-97
Residential	1990-97					0.15
	1985-89				0.25	
	1980-84			0.25		
	1979		0.20			
	1972	0.23				

The p-value for each regression's F-statistic 0.000.
There is no data for Locations 16, 17, and 18 in 1979.
At a level of significance of 0.10, the only Location variables that prove significant in the analyses are Locations 7 and 16 in 1972; Locations 4, 7, and 8 in 1979; none in 1980-84; Locations 7 and 17 in 1985-89; and Locations 4, 6, 7, 8, 16, 18, and 19 in 1990-97.
Data Source: Calculations by authors.

Leads and Lags between Transportation Scores and Housing Construction

In any one development era, a few MCDs reported large numbers of housing permits; more MCDs reported smaller numbers of permits, while most of the MCDs reported issuing no housing permits, or there are no data at all on housing permit activity. If we are trying to explain the variation in housing construction permits (dependent variable) with reference to variations in highway transportation scores (independent variable), the fact that the distribution of MCD housing permits is highly skewed with a disproportionate number of observations of zero distorts the findings. One way to remove some of the distorting effects of the skewed distribution of housing permits is to transform that distribution using common logarithms, then use the log of the standardized number of residential units authorized per MCD as the dependent variable [1].

When the transportation scores and the log of the residential construction measure are correlated, the result differs significantly from earlier results calculated without the log transformation (Table 2.2). Using the log transformation raises the correlation values (*r*) significantly (Table 2.4). On the diagonal, from lower left to upper right, the correlations for contemporary measures rise from 0.29 in the 1970s, reach a peak for the early and late 1980s (respectively 0.42 and 0.41); then drop to 0.17 in the 1990s. Below and to the right of the diagonal are measures suggesting how residential development in an earlier era may have stimulated transportation scores in later eras. For example, residential development in the 1980s seems to be highly correlated with transportation scores of the 1990s. Above and to the left of the diagonal are measures suggesting how transportation scores of the 1970s and early 1980s seem to precede housing construction of the 1980s.

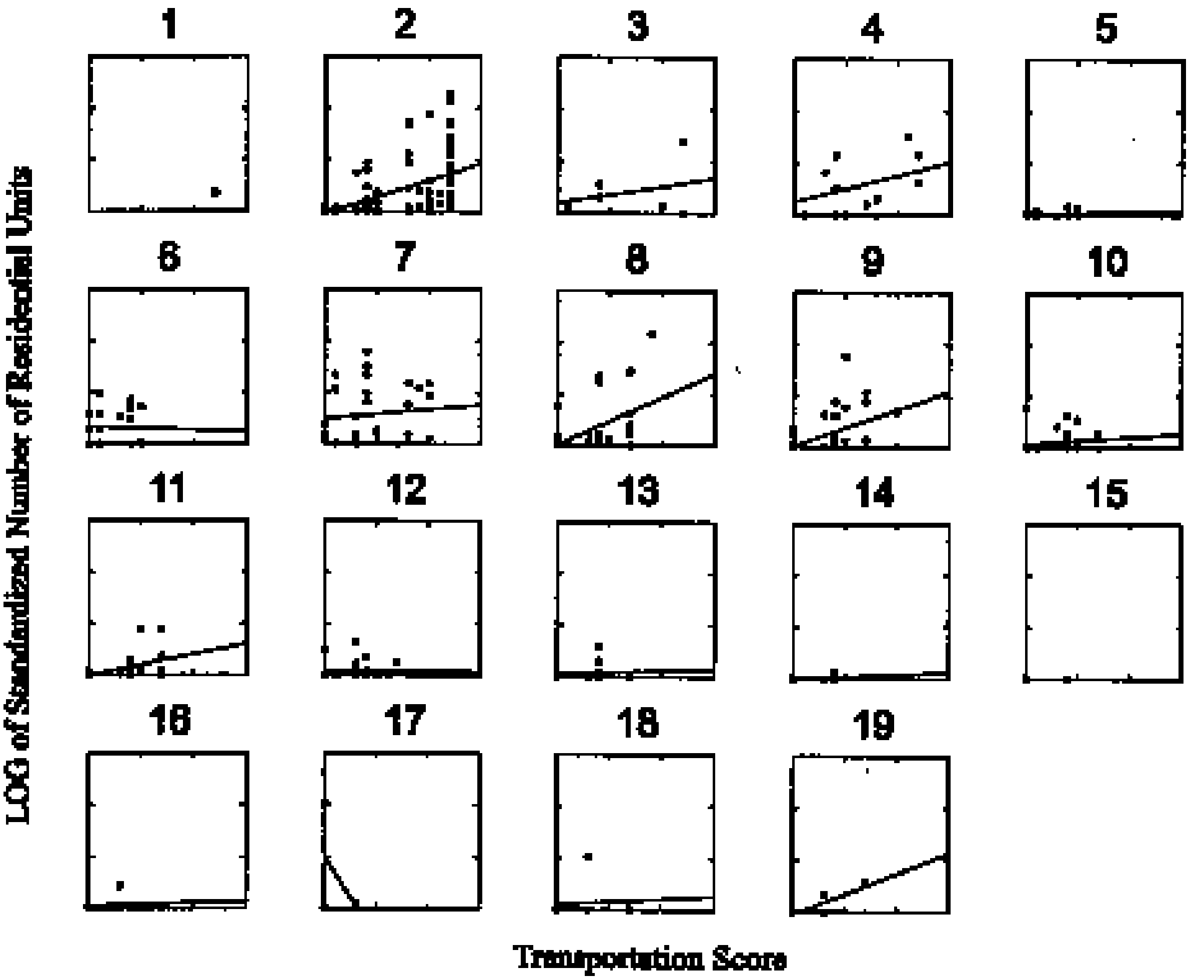
These results appear to be consistent with the argument that an MCD's transportation score in the 1970s and early 1980s had notable influence on its housing construction rates in the 1980s, but the degree of that influence diminished sharply in the 1990s. The results are also consistent with the argument that housing construction in the 1980s had a measurable influence on transportation scores of the late 1980s and 1990s. The weakest relationship is that relating transportation scores in the 1990s with the log of standardized number of residential units in the 1990s ($r = 0.17$). The apparent leads and lags of earlier decades had largely disappeared by the 1990s.

Effects of MCD Location on Rates of Housing Construction

The foregoing analysis investigated the hypothesis that variations among MCDs in standardized number of housing construction permits issued (the dependent variable) is a function of variations in transportation scores (the independent variable). Analysis of residuals from simple regressions based on this hypothesis suggested that the location of an MCD within the 24-county study area also exercised influence on rates of housing construction, an influence generally independent of MCD transportation scores.

This suggestion led to a second hypothesis, namely that variations among MCDs in standardized number of housing construction permits issued is a function of: (1) MCD transportation scores—ranging from 0 to 12; and (2) MCD location within the 24-county study area—19 categories. We performed a multiple regression analysis measuring the effects of MCD transportation scores and MCD location on the log of standardized number of MCD residential building permits issued, for each of the five time periods. The coefficient of determination (r^2) for the five time periods ranged from 0.23 in the early 1970s, dropped slightly in the late 1970s (0.20), reached a peak in the early and the late 1980s (0.25), then dropped to a low level in the 1990s (0.15) (Table 2.5). These results, compared with correlation values for the simpler model that considered only transportation scores (Table 2.4), as well as with the simple regression results (Table 2.3), reveal that adding the location variable enhances the explanatory power of the model, yet even when the coefficient of determination reaches its high point in the 1980s at 0.25, there remains unexplained 75 percent of the variation among MCDs in number of building permits issued.

Another way to investigate how transportation scores may influence housing construction rates is to partition the sample of MCDs by their locations, and then estimate separately for each location the relationship between transportation score and housing construction rates. An example was produced for the late 1980s, the era when regression analysis revealed that the relationship between the two variables was closest (Fig. 2.7). Most MCDs reporting permit-issuing activity are located within the first seven locations, that is, within the seven-county Metropolitan Council jurisdiction. Within the seven counties, the greatest number of MCDs reporting housing construction permits are within Location 2, the largely built-up urbanized area outside the two central cities but lying inside the Metropolitan Urban Services Area (MUSA) line. Most regression lines slope in the expected direction—upward to the right—disclosing a tendency for the number of new residential units to rise as transportation scores rise. Most of the locations have too few observations or observations that are too dispersed around the regression line to yield results that are highly significant (See notes on Table 2.5).



L. J. Hansen, Dept. of Geography, U of MN, 1999

Figure 2.7. Plots Showing Relationship between Transportation and log of Standardized Number of Residential Units, for Each Location Variable, 1985–89.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

Summary and Conclusions

Specific questions addressed in this chapter included the following:

- Do highways and highway improvements serving an MCD stimulate housing construction at that place? Findings: the transportation scores in the 1970s and early 1980s were significantly correlated with residential construction during the 1980s, with correlation values ranging between 0.34 and 0.38. Residential construction rates in the 1990s were essentially uncorrelated with MCD transportation scores.
- Does residential construction in an MCD promote highway improvements to serve that place? Findings: the general answer appears to be “yes” once again. Housing construction in the 1980s is significantly correlated with transportation scores of the late 1980s and 1990s, with correlation values ranging between 0.36 and 0.39.
- Is the relationship circular—as seems likely? Findings: for the 1980s, the general answer appears to be a muted “yes”; correlations between construction rates and transportation scores never exceed 0.39, or 0.43 using log of construction rates.
- Do statistical measures of lead-lag relationships remain constant through time? Findings: the effects of transportation on development seem to be greatest for transportation scores of the 1970s and construction of the 1980s; and for housing construction of the 1980s and its effects on transportation scores of the 1990s. Coefficients of determination range from 0.0 in the 1990s to 0.15 in the early 1980s.
- Do statistical measures of lead-lag relationships remain constant across locations? Findings: it is hard to tell because there are too few cases at many of the 19 locations for reliable estimates. For the locations close to the metropolitan core, it is plain that the statistical relationships vary from place to place. Adding location to the regression model raises the coefficients of determination to values between 0.15 in the 1990s and 0.25 in the 1980s.

Finally, even when construction data are appropriately transformed, and MCD location as well as transportation score is taken into account, only about a fourth of the variation in MCD housing construction rates is accounted for. The remaining 75 percent of unexplained variation is due to differences among MCDs that have not been taken into account.

Endnotes

1. Specifically, the transformation log(Y + 1) was used, where Y is the dependent variable standardized number of residential units, because in some cases the standardized number of residential units is equal to zero.

Chapter 3

Industrial Development and Transportation

Industrial Development and Transportation: Hypothesized Linkages

The relationship between industrial development and highway transportation infrastructure may be hypothesized to involve causality in either direction. As in the case of new residential development, added or improved highways may open up new areas for industrial development, and industrial enterprises locating near those arterials would then already have access to highway transportation. However, the development of new industrial enterprises (whether previously served by major transportation routes or not) generates demand for improved or expanded highway transportation infrastructure. It is not always important for industrial development to locate near other types of development, but it usually seeks good access to highway transportation routes with little congestion.

Although most MCDs reported adding at least a few residential units in each time period, the data on industrial permits disclose that more than half the places reported no industrial development during any of the time periods, so the median value of industrial development for each time period was zero. The highly skewed distribution of industrial development activity is reflected by the "**coefficient of variation**," which is the standard deviation of a distribution divided by the mean of that distribution. It is a relative measure of variability, allowing for direct comparison of the amount of variability of different variables. In comparison with the coefficients of variation for the distribution of standardized residential permits by MCD (Table 2.1), coefficients for the distribution of standardized industrial permit values are much greater (Table 3.1).

What Do the Data Show?

The scatterplot matrix portrays statistical relationships between highway infrastructure scores and standardized industrial permit values for each pairing of time periods (Fig. 3.1). There is a consistent positive correlation between transportation scores and industrial development both on and off the diagonal matrices, but the relationship appears to be weaker than the link reported between transportation scores and residential development. Correlation values along the diagonal range from 0.22 to 0.29 (Table 3.2), which are more consistent values than those observed for residential development, which ranged widely from 0.38 in the early 1980s to 0.04 in the

Table 3.1. Descriptive Statistics for the Data on Standardized Industrial Value, by Time Period, 1972 to 1994.

Time Period	Number of Cases	Maximum (in $1,000s)	Mean (in $1,000s)	Standard Deviation (in $1,000s)	Coefficient of Variation
1990-94	379	50,832,600	1,543,770	5,399,320	3
1985-89	380	415,958,000	2,846,000	22,407,200	8
1980-84	380	241,757,000	2,628,160	17,692,700	7
1979	259	169,112,000	1,724,060	12,245,300	7
1972	328	28,626,800	430,939	2,446,000	6

Median Value for each time period = $0. Standardized Industrial Value is defined as MCD industrial value divided by MCD vacant land per capita (area per population).
Data Source: U. S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file. Calculations by authors.

Table 3.2. Correlation Values of the Relationship between Transportation and Standardized Industrial Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Industrial	1990-94	0.28	0.30	0.29	0.29	*0.29*
	1985-89	0.23	0.22	0.22	*0.22*	0.22
	1980-84	0.29	0.28	*0.27*	0.27	0.27
	1979	0.24	*0.23*	0.23	0.22	0.22
	1972	*0.29*	0.29	0.28	0.28	0.28

Values are Pearson's correlation coefficients, r .
Data Source: Calculations by authors.

Table 3.3. Coefficient of Determination Values (r^2) from Regression Analysis of the Relationship between Transportation and Standardized Industrial Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Industrial	1990-94					0.08
	1985-89				0.05	
	1980-84			0.08		
	1979		0.05			
	1972	0.09				

The p-value for each regression's F-statistic = 0.000.
Data Source: Calculations by authors.

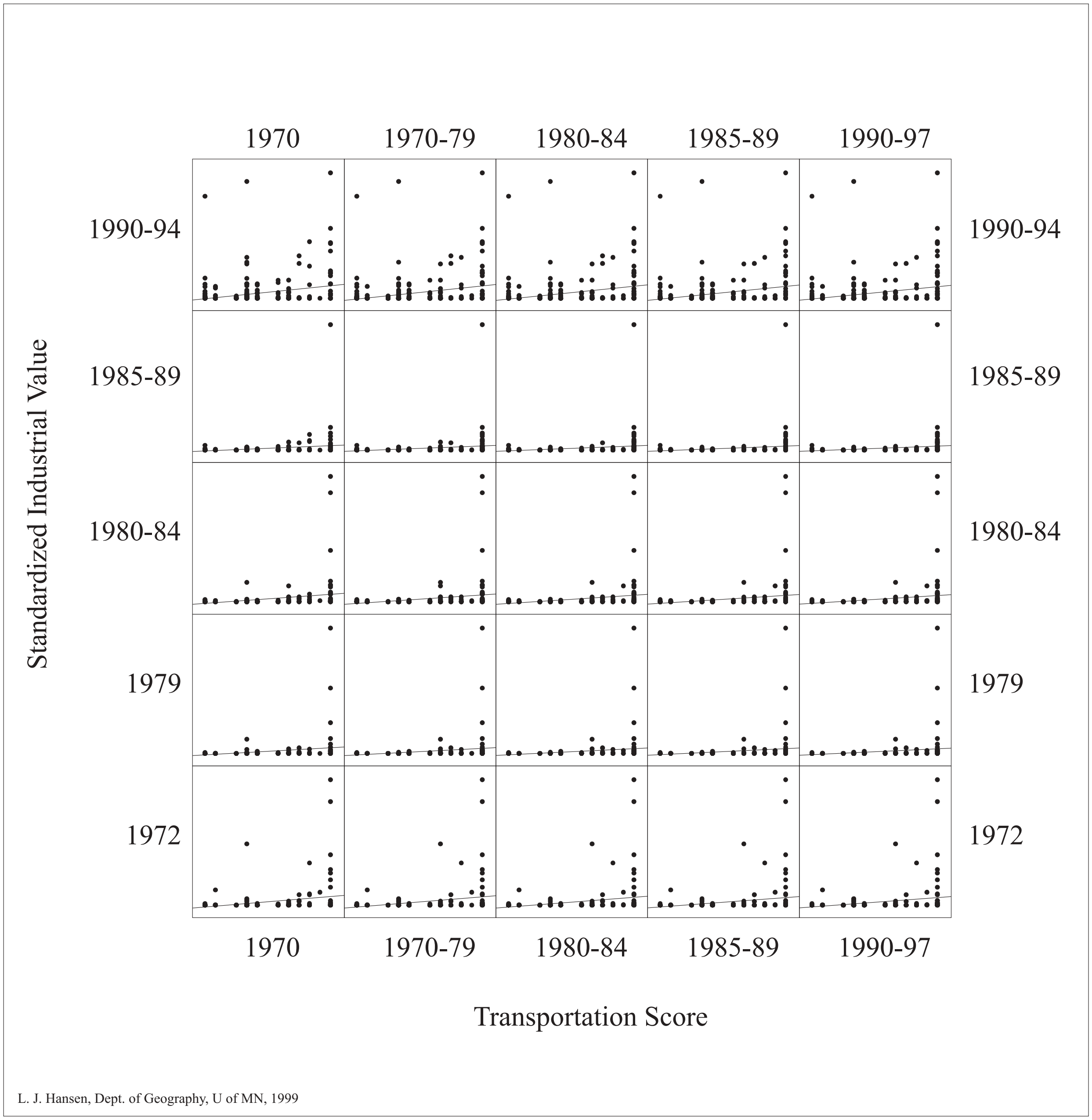


Figure 3.1. Scatterplot Matrix Showing Relationship between Transportation and Standardized Industrial Value, by Time Period, 1970–1997.
Data Source: U.S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file.

1990s. Off the diagonal, the correlation values of industrial development and transportation scores varied between 0.22 and 0.30, values revealing that early industrial development correlates with later highway improvements (below and right of diagonal), but also that early transportation scores correlate with later industrial development (above and left of diagonal).

The coefficient of determination (r^2) discloses the proportion of the variation in MCD standardized industrial development activity that is associated with or explained by variation in MCD transportation scores (Table 3.3). Whereas this coefficient varied widely from 0.00 to 0.15 in the case of residential development (Table 2.3), it varied within only a narrow range (0.05–0.09) in the case of industrial development. Despite the fact that these measures are statistically significant, they really fail to tell much about why industrial development activity varied as it did across MCDs during the study period. Even in the best case of the early 1970s, variations in transportation infrastructure accounted for less than 10 percent of the story.

Part of the unexplained story may be due to the tendency of some industrial activity to locate in small outlying cities which may not enjoy high transportation scores, but may have just one or two important accessible routes nearby, and perhaps a local population base from which to draw a labor supply. For example, in the 1990s, major industrial development occurred in Hutchinson (transportation score of 4), Winsted (score of zero), Winthrop (score of 4) and Northfield (score of zero).

Residual Unexplained Variations in Value of New Industrial Construction Permits

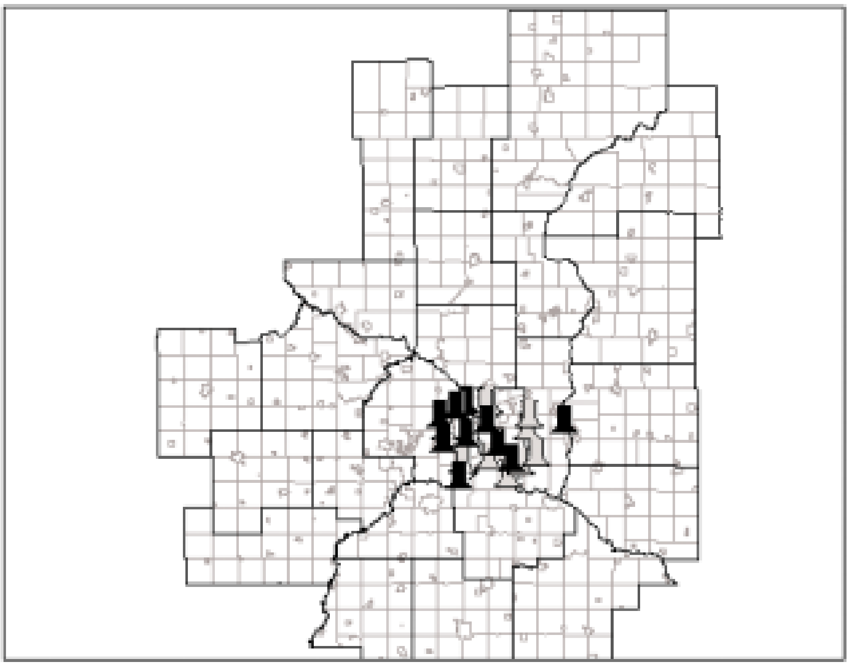
“**Transportation scores**” report how well MCDs are served by high-capacity, high-speed highways. “**Standardized industrial permit values**” report the value of new industrial construction authorized, weighted by MCD vacant land per capita. A small amount of the variation in industrial construction among MCDs is accounted for by transportation scores and the availability of vacant land, but most of the unexplained or “residual” variation is due to MCD features other than highway transportation infrastructure. Just as in the case of new housing construction, this residual unexplained variation can be allocated to MCDs using a simple linear regression model to calculate (1) the sum total of standardized industrial permit values that might have been expected to be built given an MCD’s transportation score (i.e., its predicted value) and comparing this prediction with (2) the standardized value of industrial construction actually put in place. This procedure allows us to ascertain which MCDs were over-predicted (i.e., lower value of new industrial development built than expected) and those that were under-predicted (i.e., higher value of industrial development occurred than expected).

In the early 1970s, St. Paul was under-predicted based on its transportation score by a factor of over 14, while Minneapolis in 1972 was under-predicted by a factor of almost 11 (Fig 3.2). Meanwhile, other cities such as Inver Grove Heights, Oakdale, and Golden Valley—all of which had high transportation scores and on that basis were expected to have significant industrial construction activity—reported no industrial permit values. The map of the outliers show under-predicted and over-predicted cities all located inside the seven-county core of the 24-county study area.

In the late 1970s, places such as Newport and Inver Grove Heights that had been significantly over-predicted only a few years earlier were catching up by showing a burst of industrial development activity (Fig. 3.3). Other places such as Richfield, Woodbury, Arden Hills, and Pine Springs (all with transportation scores of 12 still reported no industrial permits even though on the basis of their scores a substantial level of industrial development activity would have been expected. Meanwhile, St. Paul, Minneapolis, Bloomington, New Hope and Fridley received much more industrial development than their transportation scores forecasted. The places that were under-predicted are more dispersed than their counterparts in the early 1970s, undoubtedly a result in part of the virtual completion of the Interstate system within the study area plus the steady outward expansion of the built-up area of the Twin Cities.

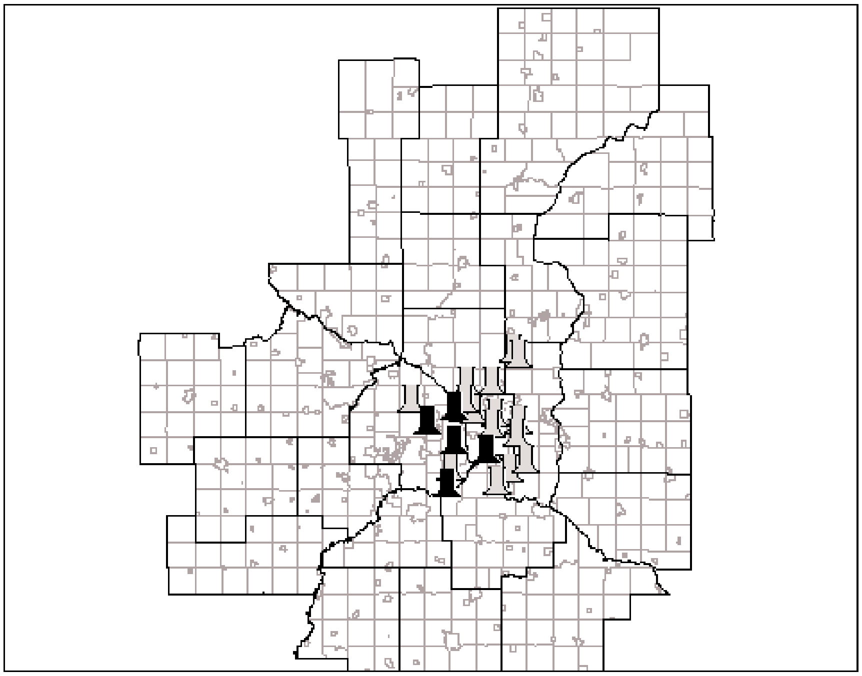
In the early 1980s, the core cities of St. Paul and Minneapolis plus several other important industrial centers continued to obtain significantly more industrial development than highway transportation scores alone would have predicted, but at the same time, selected suburban cities such as Maple Grove, Oakdale, Apple Valley, Golden Valley, Woodbury, Forest Lake and Blaine with transportation scores the same as St. Paul, Minneapolis, and Fridley showed significant industrial development, even though levels of standardized industrial permit value still fell short of predictions (Fig. 3.4).

The pattern of the early 1980s continued through the last half of that decade with Minneapolis pulling far beyond predictions and well ahead of all other MCDs in the level of its industrial development (Fig. 3.5). Over-predicted levels of industrial development occurred at several locations, both close to the core cities (Maplewood, Brooklyn Center) as well as in outlying locations (Lino Lakes, Forest Lake Twp). By the 1990s, industrial development in amounts well above levels predicted by transportation scores occurred at widely scattered locations and in places with scores of zero (Winsted, Northfield, Gaylord) as well as places directly served by major arterials (Fig. 3.6).



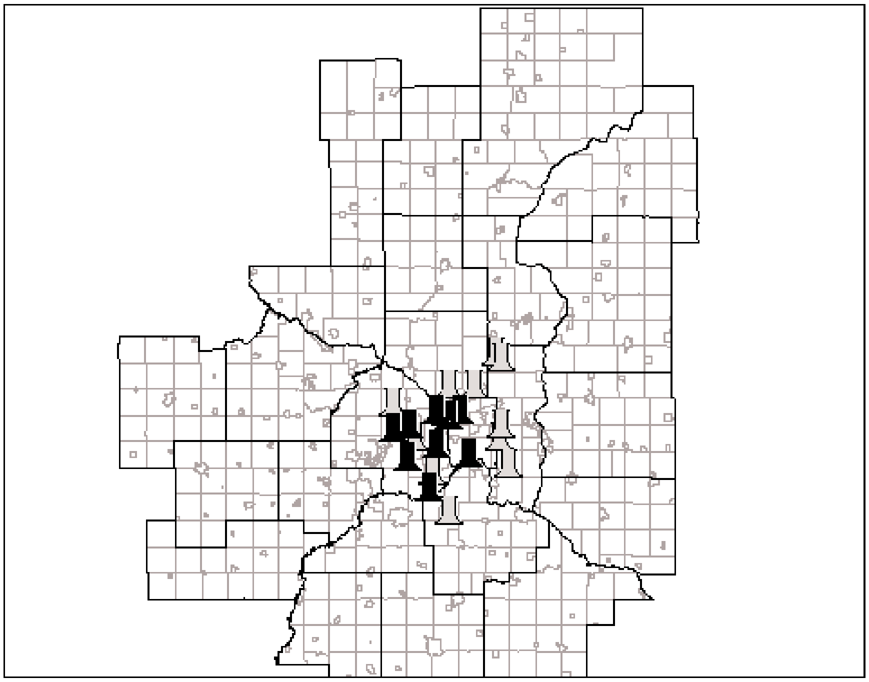
MCD	Transportation Score	Standardized Industrial Value ($)	Predicted Standardized Industrial Value ($)	Studentized Residual
St. Paul	12	28,626,839,899	1,979,070,000	14.8
Minneapolis	12	23,631,294,052	1,979,070,000	10.9
New Hope	4	13,987,723,013	372,149,000	6.1
Fridley	12	11,500,691,073	1,979,070,000	4.2
South St. Paul	10	9,616,353,993	1,577,340,000	3.5
St. Louis Park	12	8,139,638,707	1,979,070,000	2.7
Brooklyn Center	12	7,321,843,033	1,979,070,000	2.3
Bloomington	12	5,772,701,032	1,979,070,000	1.6
Bayport	1	3,478,412,703	(230,447,000)	1.6
Roseville	12	4,094,945,826	1,979,070,000	1.0
Mendota Heights	12	0	1,979,070,000	(0.9)
Richfield	12	0	1,979,070,000	(0.9)
Arden Hills	12	0	1,979,070,000	(0.9)
Woodbury	12	0	1,979,070,000	(0.9)
Pine Springs	12	0	1,979,070,000	(0.9)
Newport	12	0	1,979,070,000	(0.9)
Golden Valley	12	0	1,979,070,000	(0.9)
Oakdale	12	0	1,979,070,000	(0.9)
Inver Grove Heights	12	0	1,979,070,000	(0.9)
Shoreview	12	122,994,954	1,979,070,000	(0.8)

Figure 3.2. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1972. Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



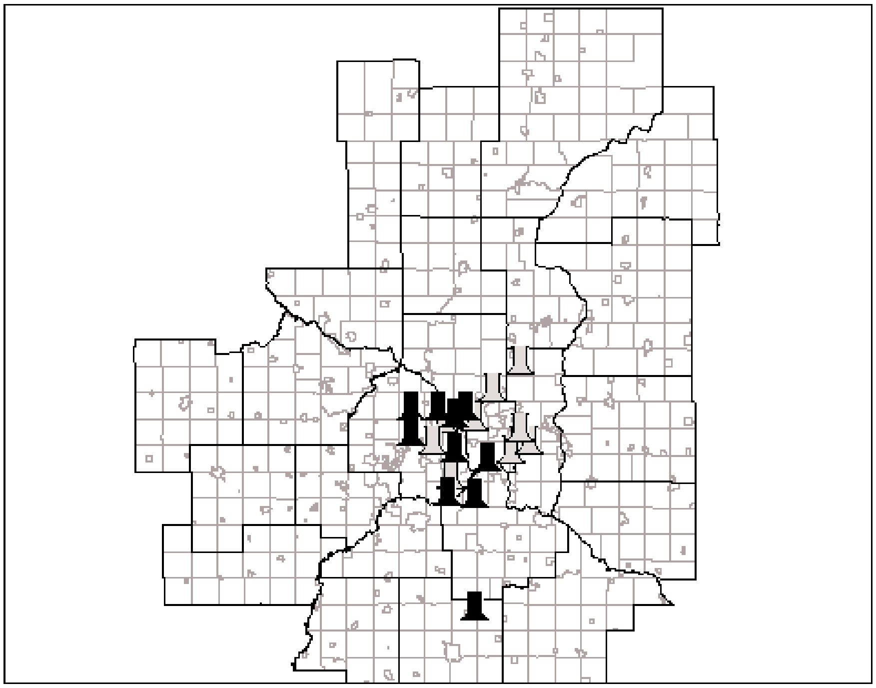
MCD	Transportation Score	Standardized Industrial Value ($)	Predicted Standardized Industrial Value ($)	Studentized Residual
St. Paul	12	169,112,463,831	6,952,960,000	26.4
Minneapolis	12	88,233,775,134	6,952,960,000	7.6
Bloomington	12	41,558,546,036	6,952,960,000	3.0
New Hope	8	19,278,201,248	3,976,510,000	1.3
Fridley	12	20,245,909,079	6,952,960,000	1.1
Little Canada	12	0	6,952,960,000	(0.6)
Mounds View	12	0	6,952,960,000	(0.6)
Forest Lake township	12	0	6,952,960,000	(0.6)
Woodbury	12	0	6,952,960,000	(0.6)
Oakdale	12	0	6,952,960,000	(0.6)
Richfield	12	0	6,952,960,000	(0.6)
Maple Grove	12	0	6,952,960,000	(0.6)
Pine Springs	12	0	6,952,960,000	(0.6)
Arden Hills	12	0	6,952,960,000	(0.6)
Vadnais Heights	12	0	6,952,960,000	(0.6)
Lino Lakes	12	6,719,757	6,952,960,000	(0.6)
Forest Lake	12	40,238,275	6,952,960,000	(0.6)
Inver Grove Heights	12	58,076,999	6,952,960,000	(0.6)
Newport	12	77,794,242	6,952,960,000	(0.6)
Blaine	12	228,460,722	6,952,960,000	(0.6)

Figure 3.3. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1979. Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



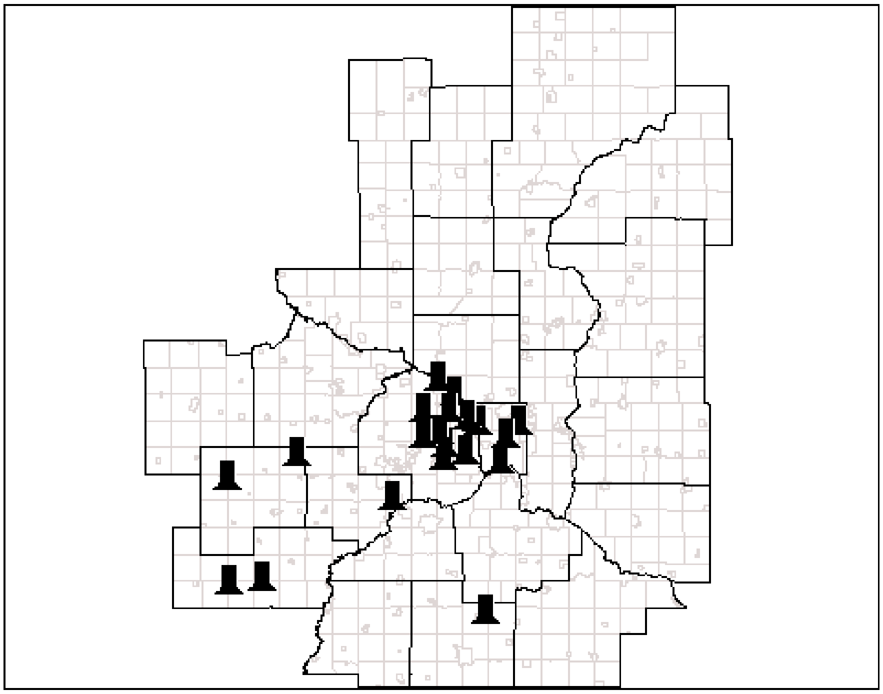
MCD	Transportation Score	Standardized Industrial Value ($)	Predicted Standardized Industrial Value ($)	Studentized Residual
St. Paul	12	241,756,791,091	12,739,000,000	18.8
Minneapolis	12	210,152,743,643	12,739,000,000	14.6
Fridley	12	99,086,215,923	12,739,000,000	5.3
New Hope	8	37,421,814,388	7,466,810,000	1.8
Bloomington	12	39,786,819,470	12,739,000,000	1.6
Plymouth	12	32,664,376,375	12,739,000,000	1.2
Hopkins	11	30,580,134,332	11,421,000,000	1.1
New Brighton	12	31,599,311,093	12,739,000,000	1.1
Shoreview	12	28,438,966,886	12,739,000,000	0.9
Richfield	12	0	12,739,000,000	(0.8)
Pine Springs	12	0	12,739,000,000	(0.8)
Lino Lakes	12	17,550,577	12,739,000,000	(0.8)
Forest Lake township	12	18,031,031	12,739,000,000	(0.8)
Blaine	12	175,643,003	12,739,000,000	(0.7)
Forest Lake	12	345,395,778	12,739,000,000	(0.7)
Woodbury	12	353,001,059	12,739,000,000	(0.7)
Golden Valley	12	467,622,593	12,739,000,000	(0.7)
Apple Valley	12	624,043,183	12,739,000,000	(0.7)
Oakdale	12	979,483,564	12,739,000,000	(0.7)
Maple Grove	12	993,675,231	12,739,000,000	(0.7)

Figure 3.4. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1980–84.
Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Standardized Industrial Value ($)	Predicted Standardized Industrial Value ($)	Studentized Residual
Minneapolis	12	415,957,987,140	12,954,900,000	61.7
Bloomington	12	75,220,563,305	12,954,900,000	2.9
St. Paul	12	56,291,408,981	12,954,900,000	2.0
Mounds View	12	51,661,505,789	12,954,900,000	1.8
Plymouth	12	46,046,633,994	12,954,900,000	1.5
Fridley	12	34,867,029,289	12,954,900,000	1.0
Northfield	0	15,582,042,157	(2,995,490,000)	0.9
Maple Grove	12	31,445,660,888	12,954,900,000	0.9
Brooklyn Park	12	28,071,135,681	12,954,900,000	0.7
Eagan	12	26,379,637,928	12,954,900,000	0.6
Richfield	12	0	12,954,900,000	(0.6)
Pine Springs	12	0	12,954,900,000	(0.6)
Arden Hills	12	0	12,954,900,000	(0.6)
Golden Valley	12	0	12,954,900,000	(0.6)
Lake Elmo	12	12,269,668	12,954,900,000	(0.6)
Forest Lake township	12	24,911,790	12,954,900,000	(0.6)
Lino Lakes	12	153,111,770	12,954,900,000	(0.6)
Maplewood	12	155,258,565	12,954,900,000	(0.6)
Oakdale	12	261,971,254	12,954,900,000	(0.6)
Brooklyn Center	12	385,498,324	12,954,900,000	(0.6)

Figure 3.5. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1985–89.
Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Standardized Industrial Value ($)	Predicted Standardized Industrial Value ($)	Studentized Residual
Minneapolis	12	50,832,637,295	4,704,790,000	10.1
Hutchinson	4	47,301,684,820	1,366,510,000	10.0
Winsted	0	41,312,421,365	(302,635,000)	8.8
Plymouth	12	28,325,869,065	4,704,790,000	4.7
Brooklyn Park	12	22,906,729,010	4,704,790,000	3.6
Little Canada	12	22,542,987,639	4,704,790,000	3.5
Fridley	12	22,175,578,985	4,704,790,000	3.4
St. Paul	12	19,131,196,678	4,704,790,000	2.8
Winthrop	4	14,616,390,814	1,366,510,000	2.6
White Bear Lake	10	16,565,978,105	3,870,220,000	2.5
Coon Rapids	12	17,184,719,697	4,704,790,000	2.4
New Hope	8	13,887,032,123	3,035,650,000	2.1
Anoka	9	14,109,017,814	3,452,930,000	2.1
Northfield	0	8,140,625,380	(302,635,000)	1.6
Maple Grove	12	13,011,772,669	4,704,790,000	1.6
Chaska	4	8,071,760,377	1,366,510,000	1.3
New Brighton	12	11,105,000,985	4,704,790,000	1.2
Gaylord	0	5,686,290,463	(302,635,000)	1.2
Golden Valley	12	10,457,000,340	4,704,790,000	1.1
St. Louis Park	12	10,241,856,463	4,704,790,000	1.1

Figure 3.6. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1990–94.
Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

Leads and Lags between Transportation Scores and Industrial Construction

In any one development era, a few MCDs reported large values of industrial permits; more MCDs reported smaller values of permits; but most MCDs reported issuing no industrial permits, or there are no data at all on industrial permit activity. If we try to explain the variation in value of industrial construction permits (dependent variable) with reference to variations in highway transportation scores (independent variable), the fact that the distribution of MCD industrial permit values is even more highly skewed than was the distribution of housing permits distorts the findings. Once again, a way to remove some of the distorting effects of the skewed distribution of value of industrial permits is to transform that distribution. In this case, the high degree of skewness suggests that the most appropriate transformation is to use the square root of an MCD's standardized industrial permit value as the dependent variable.

With this transformation, the correlation values (r) of the relationship between transportation scores and the square root of the standardized industrial value jumps upward to levels varying from 0.37 in the 1990s, to 0.46 in the early 1980s (Table 3.4). Meanwhile, correlations off the diagonal are equally impressive. Industrial permit values in earlier time periods are highly correlated with later transportation scores (below, right of diagonal); early transportation scores are highly correlated with later industrial permit values (above, left of diagonal). Variation in highway transportation infrastructure can explain part of the variation in industrial development activity among MCDs, but other differences among MCDs also play a part, including the initiatives of locally based entrepreneurs, and the aggressiveness of local government agencies in promoting local industrial development.

Effects of MCD Location on Rates of Industrial Construction

Analysis of the residuals from simple regressions based on this hypothesis suggested that the location of an MCD within the 24-county study area may also exercise influence on rates of industrial construction, an influence somewhat independent of MCD transportation scores. Most industrial enterprises want and need the resources that the built-up metropolitan area can supply, especially a large and skilled labor supply. But many of these advantages of metropolitan location diminish with distance from the core.

When MCD location (categories 1–19) is added to transportation score as another variable accounting for variations in the square root of standardized industrial value (the dependent variable), we see that the explanatory power of the regression jumps upward, with the coefficient of determination (r^2) ranging from 0.69 in the 1970s to 0.29 in the 1990s (Table 3.5). The table of

Table 3.4. Correlation Values of the Relationship between Transportatio and Square Root of Standardized Industrial Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Industrial	1990-94	0.35	0.38	0.38	0.38	*0.37*
	1985-89	0.40	0.41	0.42	*0.42*	0.41
	1980-84	0.46	0.45	*0.46*	0.45	0.45
	1979	0.41	*0.40*	0.39	0.38	0.38
	1972	*0.40*	0.41	0.40	0.39	0.39

Values are Pearson's correlation coefficients, r .
Data Source: Calculations by authors.

Table 3.5. Coefficient of Determination Values (r^2) from Multiple Regression Analysis of the Relationship of Transportation and Location to Square Root of Standardized Industrial Value, by Time Period, 1970 to 1997.

		Transportation and Location				
		1970	1970-79	1980-84	1985-89	1990-97
Industrial	1990-94					0.29
	1985-89				0.42	
	1980-84			0.65		
	1979		0.69			
	1972	0.53				

The p-value for each regression's F-statistic = 0.000.
There is no data for Locations 16, 17, and 18 in 1979.
The cases of Minneapolis and St. Paul were excluded from the analysis in 1985-89 because of their high values of Cook's Distance (D_i) = 3.4.
At a level of significance of 0.10, all Location variables prove significant in the analyses except for 1985-89, when only Location 2 proves significant.
Data Source: Calculations by authors.

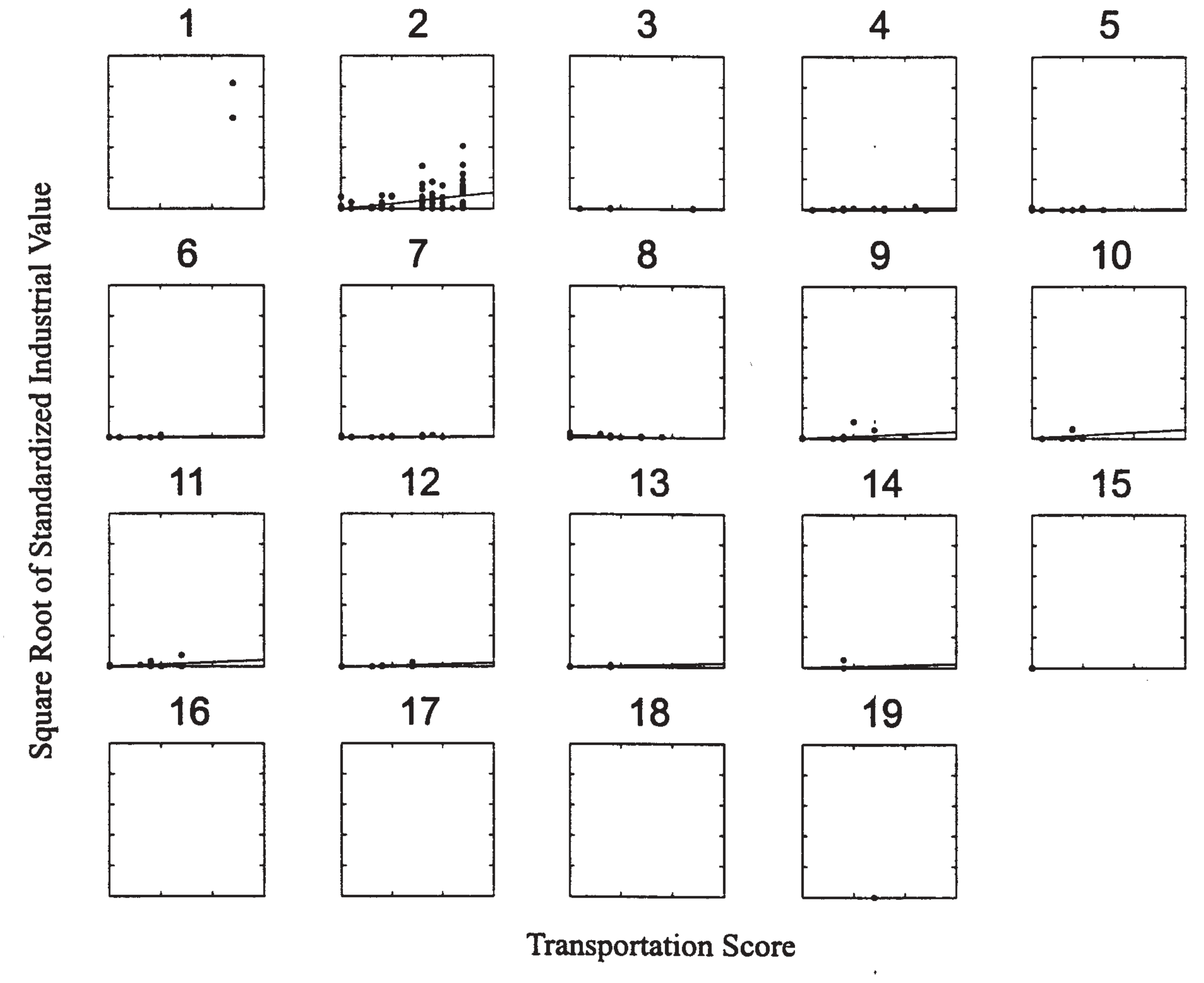
coefficients suggests that transportation scores plus location played the dominant role in accounting for variations in industrial permit values among MCDs in the early 1970s, that role increased to peak levels in the late 1970s and early 1980s, and then diminished in the 1990s. The fact that the explanatory power of this regression model diminished in the 1990s implies that the roles of transportation as measured by the transportation scores (0–12), and of location as reported by the categorical data (1–19), have been displaced by other variables, perhaps public-private partnerships, environmental attributes of MCDs, linkages among industries that require spatial proximity, expansion of specific industries which happen to be located in certain MCDs for historical reasons, or access to transportation infrastructure other than highways, such as airports.

Another way to investigate how variation in highway transportation scores may influence variations in the industrial construction measure (i.e., square root of standardized industrial value) is to partition the sample of MCDs by their locations within the 24-county study area, then estimate separately for each location the relationship between the transportation score and industrial construction measure. An example was produced for 1979, the era when regression analysis revealed that the relationship between the two variables was closest (Fig. 3.7). Most MCDs reporting permit-issuing activity are located within the first seven locations, that is, within the seven-county Metropolitan Council jurisdiction. Within the seven counties, the greatest number of MCDs reporting industrial construction permits are within Location 2, the largely built-up urbanized area outside the two central cities but lying inside the MUSA line. As in the case of the housing permit analysis, most of the regression lines slope in the expected direction—upward to the right—disclosing a tendency for new industrial activity to rise as transportation scores rise, but most locations contain too few observations to yield results that are highly significant (See notes on Table 3.5).

Summary and Conclusions

Specific questions addressed in this chapter included the following:

- Do highways and highway improvements serving an MCD stimulate industrial construction at that place? Findings: transportation scores in each of the five eras were significantly correlated with industrial permit activity. The correlation coefficients were lower than in the case of housing, but varied only modestly from one era to another.
- Does industrial construction in an MCD appear to promote highway improvements to serve that place? Findings: the general answer appears to be “yes” once again. Industrial construction in each era is significantly correlated with later transportation improvements with coefficients varying between 0.22 and 0.29.



L. J. Hansen, Dept. of Geography, U of MN, 1999

Figure 3.7. Plots Showing Relationship between Transportation and Square Root of Standardized Industrial Value, for Each Location Variable, 1979.
Data Source: U.S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits,, tape file. Calculations by authors.

- Is the relationship circular, as seems likely? Findings: yes, transportation scores for earlier eras are correlated with industrial development in later eras, with correlations ranging between 0.22 and 0.30.
- Do statistical measures of lead-lag relationships remain constant through time? Findings: the effects of transportation on development for the five eras seem to be fairly consistent through time, with correlations (r) varying between 0.22 and 0.29; and coefficients of determination (r^2) from 0.05 to 0.09. These values are statistically significant, but obviously transportation scores do not explain much. When the dependent variable is transformed and the square root of standardized industrial value is used, the correlations rise to a range of 0.37–0.46 for transportation and development in simultaneous eras, and are approximately the same for lead-lag and lag-lead correlations.
- What happens to levels of statistical explanation when location is considered? Findings: adding location to transportation score as an additional explanatory variable to account for variations in the square root of standardized industrial values raises the r^2 to levels between 0.29 and 0.69. The r^2 values rose from 0.53 in the early 1970s, reached a peak at the end of the 1970s, then dropped to lower levels in the 1990s. Evidently as the highway system improved, transportation score and location within the 24-county study area meant less as other factors rose in importance.

Chapter 4

Commercial Development and Transportation

Commercial Development and Transportation: Hypothesized Linkages

The relationship between commercial development and highway transportation infrastructure is usually hypothesized as causality in one direction: commercial development pursues population and purchasing power into newly developing areas. Added highway capacity or new highways may open up new areas for housing and for industrial development, but commercial development seldom anticipates other forms of development in any major way. It is important for major commercial development to occur near its markets—mainly people at home and people at work—and at sites with good access to important highway transportation routes.

Most MCDs reported adding at least a few residential units in each time period (Chapter 2), but as in the case of industrial development (Chapter 3) the data on commercial development permits disclose that more than half the MCDs for which data were supplied listed no commercial development during any of the five time periods, so the median value of commercial development for each time period was zero. The highly skewed distribution of commercial development, like that of industrial development, is reflected by the "**coefficient of variation**," which is the standard deviation of a distribution divided by the mean of that distribution. In comparison with the coefficients of variation for the distribution of residential permits by MCD (Table 2.1) and industrial permit values (Table 3.1), coefficients for the distribution of commercial permits are much smaller than for industrial permits but greater on average than for residential (Table 4.1). The comparison of these coefficients tells us that residential development was most widely dispersed geographically among the MCDs in the 24-county study area, commercial development was less widely distributed, and industrial development was least ubiquitous.

What Do the Data Show?

The scatterplot matrix portrays statistical relationships between highway infrastructure scores and standardized commercial permit values for each pairing of time periods (Fig. 4.1). As in the cases of residential and industrial development, there is a consistent positive correlation between transportation scores and commercial development both on and off the diagonal, but the relationship appears to be stronger than the link reported between transportation scores and industrial development (Fig. 3.1), and roughly similar to the patterns for residential development (Fig.

Table 4.1. Descriptive Statistics for the Data on Standardized Commercial Value, by Time Period, 1972 to 1994.

Time Period	Number of Cases	Maximum ($)	Mean ($)	Standard Deviation ($)	Coefficient of Variation
1990-94	379	113,914	2,729	10,888	4
1985-89	380	62,994	2,088	6,324	3
1980-84	380	17,427	849	2,221	3
1979	259	234,240	1,615	14,754	9
1972	328	9,058	200	955	5

Median Value for each time period = $0. Standardized Commercial Value is defined as MCD commercial value divided by MCD population density (population per square mile). Data Source: U. S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file. Calculations by authors.

Table 4.2. Correlation Values of the Relationship between Transportation and Standardized Commercial Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Commercial	1990-94	0.16	0.16	0.16	0.16	*0.16*
	1985-89	0.38	0.37	0.39	*0.38*	0.38
	1980-84	0.41	0.42	*0.42*	0.41	0.43
	1979	0.11	*0.10*	0.16	0.16	0.16
	1972	*0.31*	0.31	0.31	0.33	0.33

Values are Pearson's correlation coefficients, *r* .
Data Source: Calculations by authors.

Table 4.3. Coefficient of Determination Values (r^2) from Regression Analysis of the Relationship between Transportation and Standardized Commercial Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Commercial	1990-94					0.02
	1985-89				0.14	
	1980-84			0.18		
	1979		0.01			
	1972	0.10				

The p-value for each regression's F-statistic = 0.00, except for 1979 with a p-value = 0.10.
Data Source: Calculations by authors.

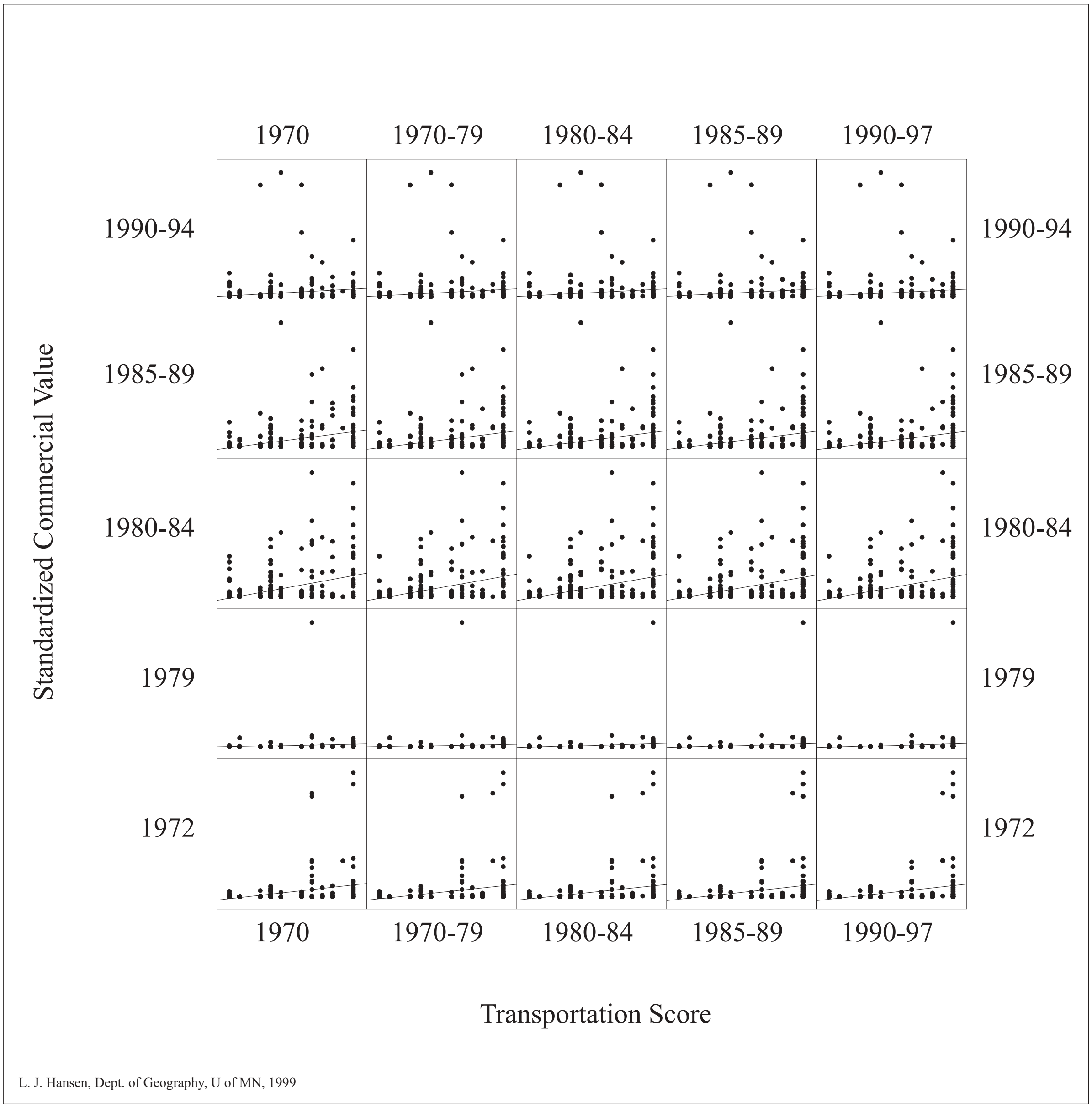


Figure 4.1. Scatterplot Matrix Showing Relationship between Transportation and Standardized Commercial Value, by Time Period, 1970–1997.
Data Source: U.S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file.

2.1). Correlation values along the diagonal range from 0.10 to 0.42 (Table 4.2). The highest correlation coefficient on the diagonal is more than four times the lowest—a wide range similar to that for residential development (Table 2.2). The correlation coefficients relating transportation scores with industrial development varied within a much narrower range (Table 3.2). The correlation coefficients along the diagonal, relating highway transportation scores and contemporary commercial development, reach their highest levels in the 1980s, and are lower in the 1970s and 1990s, sometimes much lower (Table 4.2).

Off the diagonal, the commercial development of the early 1970s was significantly correlated with later highway improvements (below, right of diagonal). The same can be said about commercial development in the 1980s, which also is correlated with later highway improvements. On the other hand, transportation improvements of the 1970s are highly correlated with commercial development investments of the 1980s (above, left of diagonal). These are results we might expect if highway planning, expansion, and building anticipated development while at the same time responded to demand created by earlier residential and commercial development.

The coefficient of determination (r^2) discloses the proportion of the variation in standardized commercial development activity among MCDs that is associated with or explained by variations in MCD transportation scores (Table 4.3). This coefficient varied between 0.00 and 0.15 in the case of residential development (Table 2.3), and between 0.05 and 0.09 in the case of industrial development (Table 3.3). In the case of commercial development, the coefficients ranged from 0.01 to 0.18. The coefficients for residential development and commercial development, even though modest in size, reach their highest levels in the 1980s. The coefficients for industrial development are generally low across the board. The modest peaks in the coefficients for residential and commercial development in the 1980s imply that the quality of highway transportation infrastructure reached its peak level of influence on development activity in the 1980s, then gave way in the 1990s to other factors and variables that varied from MCD to MCD.

Despite the fact that these measures are statistically significant, they really fail to tell us much about why commercial development activity varied in intensity as it did across MCDs during the five eras of the study period. Even in the best case of the early 1980s, variations in transportation infrastructure accounted for only 18 percent of the story.

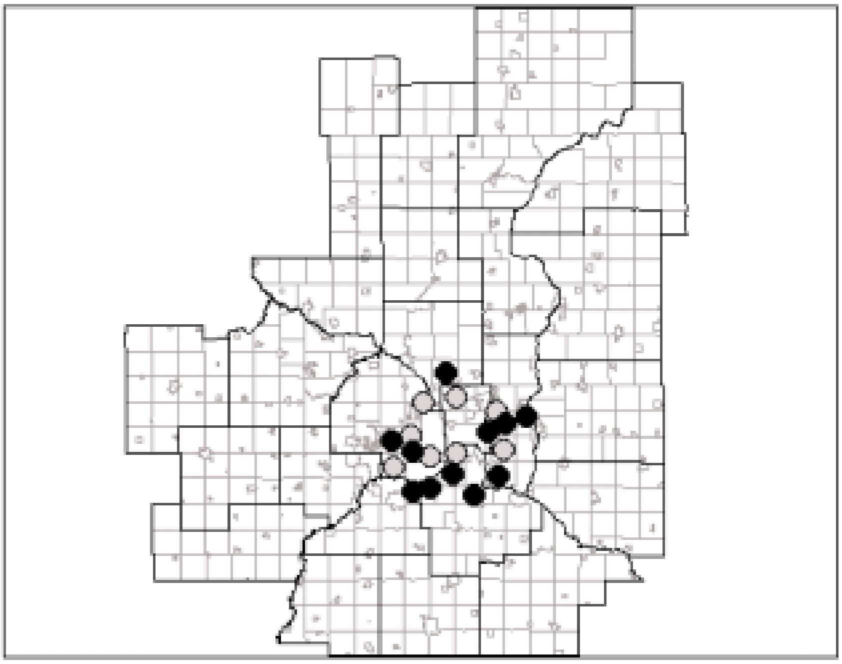
Residual Unexplained Variations in Value of New Commercial Construction Permits

"**Transportation scores**" report how well MCDs are served by high-capacity, high-speed highways. "**Standardized commercial permit values**" report new commercial construction authorized, weighted by MCD population density. A small amount of the variation in commercial construction among MCDs is accounted for by transportation scores and population density, but most of the unexplained or "residual" variation is a result of MCD features other than highway transportation infrastructure. Just as in the case of new housing construction and industrial development, this residual unexplained variation can be allocated to MCDs using a simple linear regression model that calculates (1) the size of standardized commercial permit values that might have been expected given an MCD's transportation score (i.e., a predicted value), and comparing this prediction with (2) the standardized value of new commercial development actually put in place. This procedure allows us to ascertain which MCDs were over-predicted (i.e., lower values of new commercial development than expected) and those that were under-predicted (i.e., higher values of commercial development than expected).

In the early 1970s, a number of Twin Cities suburbs such as Blaine, Minnetonka, Rosemount, and Lake Elmo received substantially higher values of commercial development than the model based on transportation scores alone predicted (Fig. 4.2). In contrast, Richfield, Brooklyn Center and St. Louis Park—already well served by commercial services and with high transportation scores—received less new commercial development than predicted.

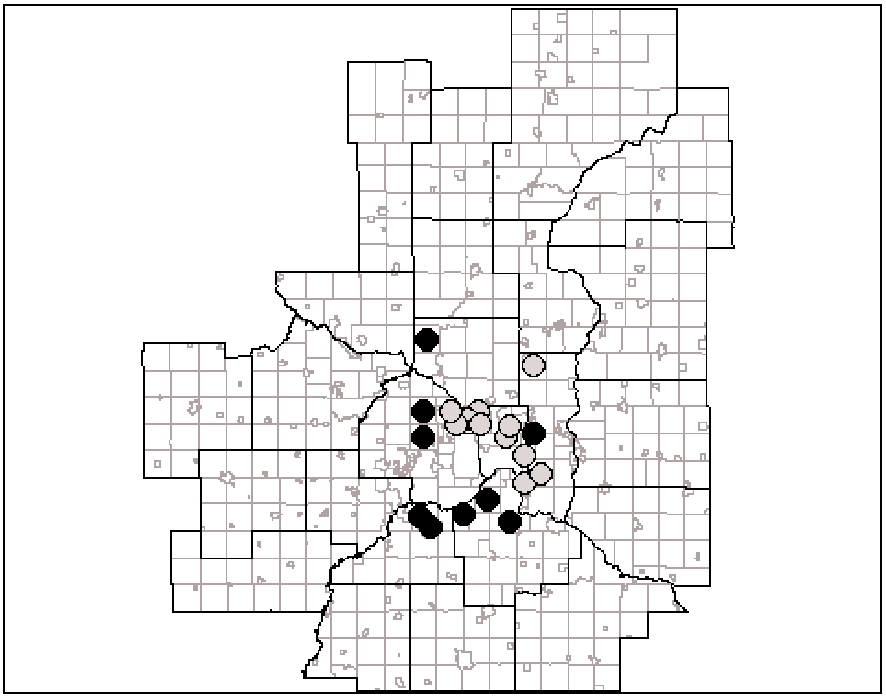
The high positive residuals of the late 1970s (i.e., higher values of development than predicted) occur mainly in outlying suburbs on the south, west, and northwest sides of the Twin Cities core, in areas that were fast growing and above average in income (Fig. 4.3). Several suburbs south of the Minnesota and Mississippi Rivers received substantially more commercial development than the model predicted, perhaps in anticipation of the completion of Interstates 35E and 494. Those MCDs that received less commercial development than the model predicted are clustered to the north and east of the central cities.

The map of the early 1980s displays a widely scattered pattern of positive residuals, reflecting the ease of movement throughout the area, the widely scattered residential developments throughout the area by that time, and perhaps the increasing degree to which local governments had begun working with developers and investors to expand commercial activity on behalf of local fiscal agendas (Fig. 4.4). Many of the MCDs with modest transportation scores received significant commercial development. This pattern continued into the late 1980s, with many of the same MCDs again receiving higher values of commercial development than the model pre-



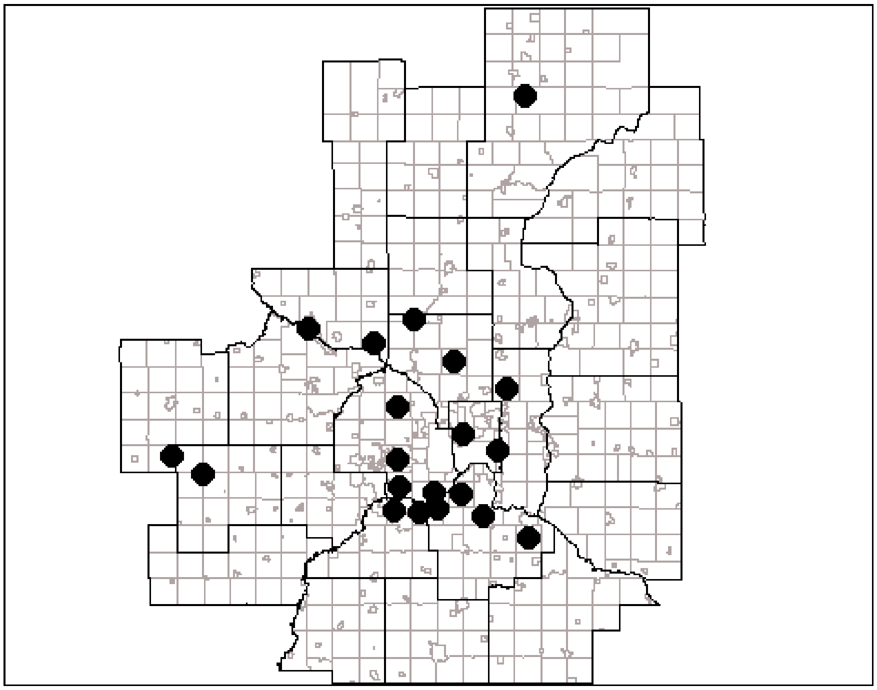
MCD	Transportation Score	Standardized Commercial Value ($)	Predicted Standardized Commercial Value ($)	Studentized Residual
Blaine	12	9,058	847	10.5
Minnetonka	12	8,230	847	9.2
Rosemount	8	7,559	511	8.6
Lake Elmo	8	7,333	511	8.3
Savage	8	2,644	511	2.4
Baytown township	8	2,534	511	2.2
Maplewood	12	2,809	847	2.2
Edina	11	2,610	763	2.1
Cottage Grove	8	2,116	511	1.8
Burnsville	12	2,190	847	1.5
Eagan	8	1,533	511	1.1
Mendota Heights	12	0	847	(0.9)
Pine Springs	12	0	847	(0.9)
Woodbury	12	0	847	(0.9)
Shoreview	12	0	847	(0.9)
Eden Prairie	12	0	847	(0.9)
Oakdale	12	6	847	(0.9)
St. Louis Park	12	37	847	(0.9)
Brooklyn Center	12	51	847	(0.9)
Richfield	12	104	847	(0.8)

Figure 4.2. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1972. Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Standardized Commercial Value ($)	Predicted Standardized Commercial Value ($)	Studentized Residual
Eagan	8	234,240	2,796	90.7
Shakopee	8	21,151	2,796	1.3
Burns township	1	16,312	65	1.1
Rosemount	11	17,935	3,966	1.0
Plymouth	12	15,410	4,356	0.8
Maple Grove	12	13,779	4,356	0.6
Prior Lake	4	8,215	1,235	0.5
Burnsville	12	10,760	4,356	0.4
Pine Springs	12	9,902	4,356	0.4
Forest Lake township	12	0	4,356	(0.3)
Mounds View	12	0	4,356	(0.3)
Little Canada	12	0	4,356	(0.3)
Newport	12	0	4,356	(0.3)
Vadnais Heights	12	0	4,356	(0.3)
Fridley	12	44	4,356	(0.3)
Brooklyn Center	12	64	4,356	(0.3)
Maplewood	12	115	4,356	(0.3)
Woodbury	12	121	4,356	(0.3)
New Brighton	12	122	4,356	(0.3)
Brooklyn Park	12	209	4,356	(0.3)

Figure 4.3. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1979. Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Standardized Commercial Value ($)	Predicted Standardized Commercial Value ($)	Studentized Residual
Savage	8	17,427	1,782	8.5
Minnetonka	12	15,943	2,799	7.0
Eden Prairie	12	12,481	2,799	5.0
Shakopee	8	10,661	1,782	4.5
Becker	5	9,025	1,019	4.1
Marshan township	4	8,118	765	3.7
Burnsville	12	10,093	2,799	3.7
Elk River	9	8,350	2,036	3.2
St. Francis	4	6,987	765	3.1
Cedar Mills	0	5,692	(252)	3.0
Bloomington	12	8,342	2,799	2.8
Ham Lake	8	7,347	1,782	2.8
Rosemount	11	7,833	2,545	2.7
Sandstone	7	6,765	1,528	2.6
Maple Grove	12	7,767	2,799	2.5
Eagan	12	7,427	2,799	2.3
Hutchinson	4	5,129	765	2.2
Maplewood	12	7,067	2,799	2.1
Roseville	12	7,064	2,799	2.1
Hugo	4	4,604	765	2.0

Figure 4.4. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1980–84.
Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

dicted (Fig. 4.5). These holdovers included Elk River, Eagan, Eden Prairie, Savage, Maple Grove, Burnsville, and Maplewood.

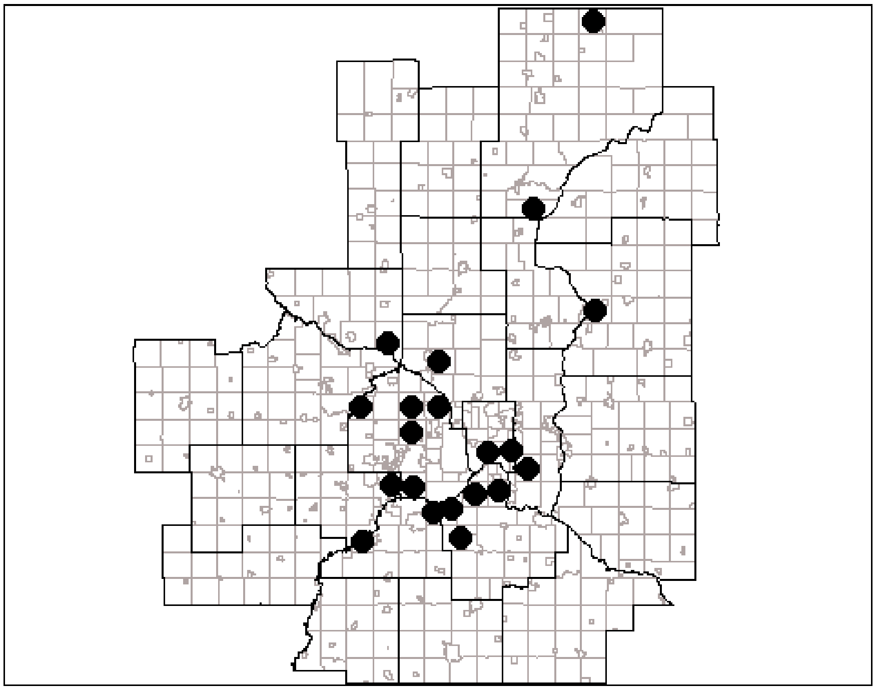
An even more sprawling pattern of commercial development occurred in the 1990s. Only two of the MCDs on the high-positive residuals list of the 1980s remained on the list into the next decade—Plymouth, with a transportation score of 12, and Elk River, whose score remained at 9 (Fig. 4.6). Four MCDs with transportation scores of zero—Waconia township, Dundas, Farmington town (WI), and Amery (WI)—made the list of the largest positive outliers.

Leads and Lags between Transportation Scores and Commercial Construction

As in the case of industrial development, most MCDs in the study area reported issuing no commercial development building permits. We know this because the median value of commercial permits was zero in each time period (Table 4.1). If we try to account for the variation in value of commercial construction permits (dependent variable) with reference to variations in highway transportation scores (independent variable), the fact that the distribution of MCD commercial permits is highly skewed with a majority of zero values distorts our findings. Once again, the way to remove some of the distorting effects of the highly skewed distribution of value of commercial permits is to transform that distribution. In this case, the form of the skewness suggested that the most appropriate transformation is to use the log of an MCD's standardized commercial permit value as the dependent variable [1].

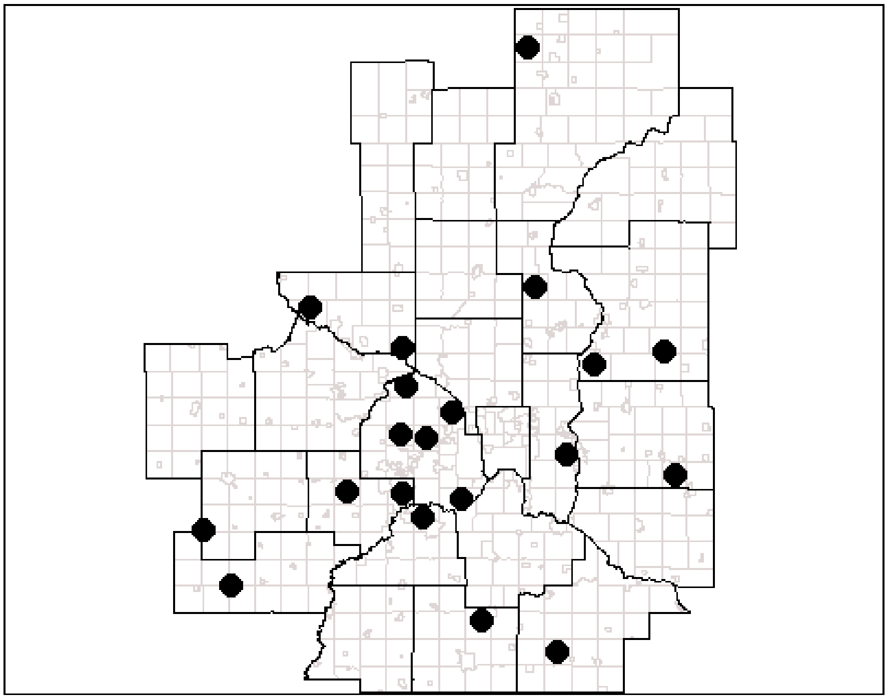
Correlation values of the relationships between transportation scores and the log of the standardized commercial values for each time period are surprisingly high, ranging from 0.38 in the 1990s to 0.52 in the early 1970s (Table 4.4). The correlation coefficients off the diagonal are similarly high. The bottom row of coefficients range from 0.52 to 0.55, illustrating how high levels of commercial development in the early 1970s are associated with high transportation scores in each subsequent era.

Since all the coefficients are reasonably high, it appears that commercial development both leads and lags improvements and quality of highway transportation infrastructure. That is, these high coefficients are consistent with the idea that places that enjoy high transportation scores are highly likely to have high values for commercial building permits issued, and vice versa. However, we may also note that the correlation coefficients for development preceding transportation (0.40–0.55) are slightly higher than those for transportation leading development (0.34–0.49).



MCD	Transportation Score	Standardized Commercial Value ($)	Predicted Standardized Commercial Value ($)	Studentized Residual
St. Lawrence township	5	62,994	2,478	12.2
Plymouth	12	49,309	6,982	7.8
Elk River	9	39,631	5,052	6.2
Eagan	12	36,764	6,982	5.3
Eden Prairie	12	30,078	6,982	4.0
St. Paul	12	25,369	6,982	3.2
Savage	8	22,756	4,408	3.2
Woodbury	12	23,471	6,982	2.9
Kerrick township	3	16,972	1,191	2.7
Maple Grove	12	22,089	6,982	2.6
Lakeville	10	19,199	5,695	2.3
Greenfield	0	12,427	(740)	2.3
Inver Grove Heights	12	19,588	6,982	2.2
Andover	4	14,264	1,834	2.1
Burnsville	12	17,365	6,982	1.8
Rock Creek	7	13,197	3,765	1.6
Maplewood	12	16,160	6,982	1.6
St. Croix Falls town (WI)	4	10,921	1,834	1.6
Brooklyn Park	12	15,819	6,982	1.5
Chanhassen	8	13,003	4,408	1.5

Figure 4.5. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1985–89.
Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Standardized Commercial Value ($)	Predicted Standardized Commercial Value ($)	Studentized Residual
Wanamingo township	5	113,914	2,996	12.2
Bremen township	3	102,415	2,069	10.6
Branch	7	102,537	3,923	10.4
Eau Galle town (WI)	7	58,795	3,923	5.3
Bloomington	12	51,917	6,240	4.4
Shakopee	8	37,011	4,386	3.1
Elk River	9	31,515	4,850	2.5
Waconia township	0	21,717	679	2.0
Winthrop	4	19,755	2,533	1.6
Plymouth	12	21,421	6,240	1.4
Chanhassen	8	16,909	4,386	1.2
Brooklyn Park	12	17,960	6,240	1.1
Dundas	0	12,374	679	1.1
Farmington town (WI)	0	11,872	679	1.0
Stewart	4	13,694	2,533	1.0
Medina	4	13,213	2,533	1.0
West Lakeland township	10	15,823	5,313	1.0
Rogers	7	13,446	3,923	0.9
Amery (WI)	0	9,588	679	0.8
Clear Lake	5	10,831	2,996	0.7

Figure 4.6. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1990–94.

Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

Table 4.4. Correlation Values of the Relationship between Transportation and LOG of Standardized Commercial Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Commercial	1990-94	0.34	0.38	0.39	0.38	*0.38*
	1985-89	0.43	0.45	0.46	*0.45*	0.45
	1980-84	0.37	0.40	*0.41*	0.40	0.41
	1979	0.49	*0.49*	0.50	0.49	0.50
	1972	*0.52*	0.53	0.54	0.54	0.55

Values are Pearson's correlation coefficients, r .
Data Source: Calculations by authors.

Table 4.5. Coefficient of Determination Values (r^2) from Multiple Regression Analysis of the Relationship of Transportation and Location to LOG of Standardized Commercial Value, by Time Period, 1970 to 1997.

		Transportation and Location				
		1970	1970-79	1980-84	1985-89	1990-97
Commercial	1990-94					0.19
	1985-89				0.31	
	1980-84			0.25		
	1979		0.32			
	1972	0.37				

The p-value for each regression's F-statistic = 0.000.
There is no data for Locations 16, 17, and 18 in 1979.
At a level of significance of 0.10, all Location variables except Locations 2 and 4 prove significant in the analysis in 1972; only Location 4 proves significant in 1979; all Locations except Locations 2, 4, 7, 11, and 16 prove significant in 1980-84; all Locations except Locations 2, 8, 9, and 16 prove significant in 1985-89; and only Location 1 proves significant in 1990-94.
Data Source: Calculations by authors.

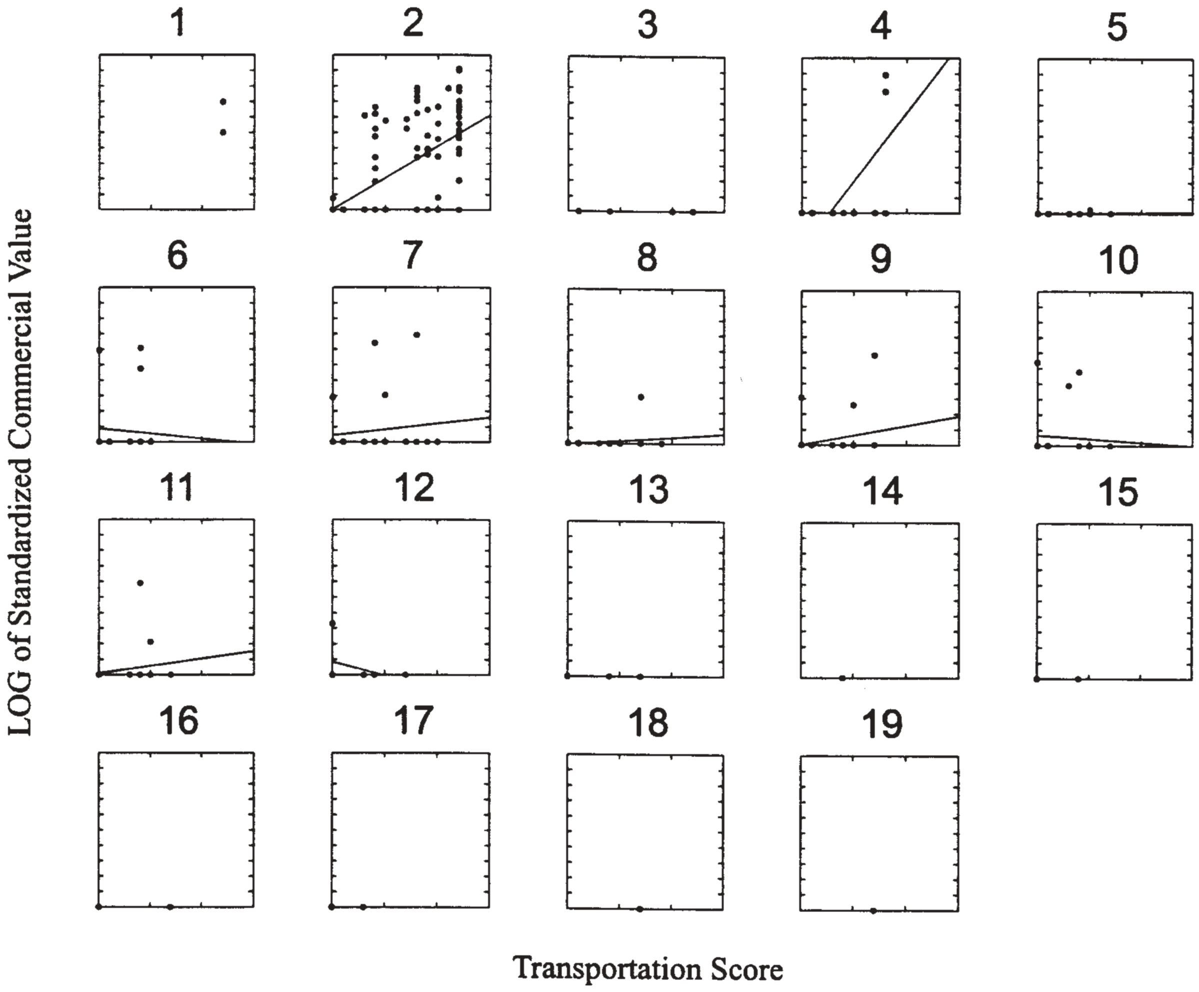
Effects of MCD Location on Rates of Commercial Construction

The correlation analysis concluded that commercial development apparently both leads and lags improvements and quality of highway transportation infrastructure. The maps of residuals seem to display a composite of several patterns: over-prediction in close-in suburbs undergoing rapid population growth and residential construction (early 1970s); and under-prediction in prosperous southern and western suburbs of the Twin Cities suburbs (late 1970s and early 1980s), and at scattered locations at and beyond the edges of the built-up metropolitan area (after 1980).

Analysis of the residuals from simple regressions suggested that the location of an MCD within the 24-county study area may also exercise influence on rates of commercial construction, an influence somewhat independent of MCD transportation scores. When MCD location is added to transportation score as another variable accounting for variations in the log of standardized commercial value (the dependent variable), we see that the explanatory power of the regression jumps upward. The coefficient of determination (r^2) is highest in the early 1970s at 0.37, then generally declines to a low of 0.19 in the 1990s (Table 4.5).

The table of coefficients suggests that transportation scores plus location played an important role in accounting for variations in commercial permit values among MCDs in the early 1970s, but that role diminished to a low level in the 1990s. The fact that the explanatory power of transportation scores and location diminished in the 1990s implies that the roles of transportation as measured by the transportation scores (0–12), and of location as reported by the categorical data (1–19), have been displaced by other variables as in the case of industrial development—possibly some combination of public-private partnerships, environmental attributes of MCDs, linkages among commercial and industrial enterprises that require spatial proximity, expansion of specific commercial sectors which happen to be located in certain MCDs for historical reasons, or access to transportation infrastructure other than highways.

As a final analytical step, regressions were plotted separately for each of the 19 locations for 1972—the year when the coefficient of determination from the regression including location was at its maximum (Fig. 4.7). Location 2, the urbanized and urbanizing area containing the 88 MCDs outside the two central cities but well within the MUSA line, showed the most marked relationship between transportation scores and the log of the standardized value of commercial development. The other 18 locations had too little commercial construction, or observations that were too dispersed to yield a reliable trend.



L. J. Hansen, Dept. of Geography, U of MN, 1999

Figure 4.7. Plots Showing Relationship between Transportation and log of Standardized Commercial Value, for Each Location Variable, 1972.

Data Source: U.S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file. Calculations by authors.

Summary and Conclusions

Specific questions addressed in this chapter included the following:

- Do highways and highway improvements serving an MCD stimulate commercial construction at that place? Findings: transportation scores in each of the five eras were significantly correlated with commercial permit values from the same era. The correlations are highest for the 1980s, reaching a value of 0.42 in the early 1980s.
- Does commercial construction in an MCD appear to promote highway improvements to serve that place? Findings: the general answer appears to be "yes" once again. Commercial construction in each era is significantly correlated with later transportation improvements, with correlations highest for the 1980s.
- Is the relationship circular—as seems likely? Findings: transportation scores for earlier eras are correlated with commercial development in later eras, and vice versa. The commercial developments of the 1980s are most strongly correlated with transportation scores before, during, and following the 1980s, with values ranging from 0.37 to 0.43.
- Do statistical measures of lead-lag relationships remain constant through time? Findings: no, they vary—correlation coefficients relating commercial construction values and transportation scores are lowest for construction in the late 1970s and in the 1990s, and highest for commercial construction values of the 1980s. The coefficients of determination (r^2) reach their highest value of 0.18 in the early 1980s. When the log of standardized commercial values from each era are correlated with transportation scores of each era, earlier construction has high correlations with later transportation scores; early transportation scores have lower correlations with later construction values. This finding suggests that commercial construction leads transportation improvements slightly more than the reverse.
- What happens to levels of statistical explanation when location is considered? Findings: adding locations to transportation scores to account for variations in the log of standardized commercial values raises the r^2 to levels as high as 0.37. The r^2 value was highest in the early 1970s, then dropped to 0.19 in the 1990s. Just as in the cases of both residential development and industrial development, as the highway system improved, transportation scores and location within the 24-county study area declined in importance in the 1990s as other factors rose in importance.

Endnotes

1. Specifically, the transformation log(Y + 1) was used, where Y is the dependent variable standardized value of commercial permits, because in some cases the standardized value of commercial permits is equal to zero.

Chapter 5

Office Development and Transportation

Office Development and Transportation: Hypothesized Linkages

What is the functional linkage and mutual geographical occurrence between the quality of highway arterials within or near an MCD, and the amount of incremental office development in the MCD? Are correlations likely to resemble those for residential, industrial, and commercial development? Or do they differ?

Some office construction has been stimulated within the downtowns of central cities as part of public-private partnerships to shore up the cities' economic vitality and to stabilize their tax base. Downtowns are well-served by major arterials, but the location of these office buildings at locations downtown rather than elsewhere in the study area reflects a desire in many lines of business (e.g., money-center banking, advertising, media) and professional activity (e.g., legal, medical, government) for face-to-face interaction. Another share of general office construction occurs in outlying areas as speculative investments, and still other office construction simply reflects the needs of specific organizations for more space, a different kind of space, or space at a different location.

When office space is planned, we expect that where it ends up being built depends at least in part on accessibility, along with the availability of vacant building sites that have been zoned to accommodate it. To the extent that local zoning codes anticipate that office tenants would want and need highway access, and be interested in highly visible sites along highway arterials, the location of office buildings will reflect ideas and expectations that are embedded in local land use zoning codes.

If sites that are zoned for offices are available for development in a rapidly developing suburban area, we would expect that in time many of them would support offices. If office development proceeds at such sites at a rapid pace, the traffic that is generated could lead to expansion of arterials to serve those office locations. Moreover, offices often are located adjacent to commercial activity, and it is not uncommon for commercial and office activity to expand together because they usually provide clientele for each other. It seems unlikely that transportation scores in themselves would be directly dependent on office development, although local traffic management infrastructure is frequently modified to accommodate traffic to and from a major office building or office complex.

In each of the five development eras, more than half the MCDs reported no office building permits, so the median value of office development for each time period was zero (Table 5.1). The MCDs that reported positive permit values for office construction recorded widely varying amounts in the early 1970s. That variability, as reported by the coefficient of variation (i.e., standard deviation divided by the mean), declined in the late 1970s and 1980s, then returned to high levels in the 1990s. When office construction varies widely in value and occurs at only a few locations rather than throughout much of the study area as does residential construction, the coefficient of variation will be high.

What Do the Data Show?

The scatterplot matrix portrays statistical relationships between highway infrastructure scores and office permit values for each pairing of time periods (Fig. 5.1). As in the cases of the other classes of development, there are obvious positive correlations between transportation scores and office development both on and off the diagonal, but the relationships appear to be less dramatic than the patterns for residential development (Fig. 2.1) or commercial development (Fig. 4.1). The scatterplots resemble those for industrial development (Fig. 3.1).

Correlation values along the diagonal range from 0.18 to 0.32, with the highest value on the diagonal less than twice the value of the lowest (Table 5.2). Only the case of industrial development had a narrower range across the five development eras (Table 3.2). The correlation coefficients along the diagonal, relating highway transportation scores and contemporary office development, reach their highest levels in the late 1970s and early 1980s, but the differences in correlations among the eras are small. This finding may mean that although office construction in MCDs and transportation scores for MCDs are significantly correlated, there seems to be only modest differences from era to era in this statistical relationship, regardless of any directions of causation. Of course transportation scores and geographical patterns of office construction may both depend on third factors regulating the location and intensity of development instead of or in addition to any lead-lag locational influences they wield on one another.

Off the diagonal, the office development of early eras was significantly correlated with later highway improvements (below, right of diagonal) (Table 5.2). On the other hand, transportation improvements of the early years are significantly correlated with office development investments of later eras (above, left of diagonal). Local zoning codes are used in forecasting highway traffic and anticipating highway traffic. These are results we might expect if highway plan-

Table 5.1. Descriptive Statistics for the Data on Office Value, by Time Period, 1972 to 1994.

Time Period	Number of Cases	Maximum ($)	Mean ($)	Standard Deviation ($)	Coefficient of Variation
1990-94	379	350,475,800	1,938,756	18,454,916	10
1985-89	380	314,951,312	3,036,553	20,064,083	7
1980-84	380	191,314,171	2,658,235	16,061,448	6
1979	260	51,628,482	857,946	4,245,929	5
1972	329	29,082,106	174,429	1,693,934	10

Median Value for each time period = $0.
Data Source: U. S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file. Calculations by authors.

Table 5.2. Correlation Values of the Relationship between Transportation and Office Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Office	1990-94	0.20	0.19	0.19	0.18	*0.18*
	1985-89	0.31	0.29	0.30	*0.29*	0.29
	1980-84	0.35	0.33	*0.32*	0.32	0.31
	1979	0.35	*0.32*	0.31	0.30	0.30
	1972	*0.21*	0.19	0.19	0.19	0.19

Values are Pearson's correlation coefficients, r .
Data Source: Calculations by authors.

Table 5.3. Coefficient of Determination Values (r^2) from Regression Analysis of the Relationship between Transportation and Office Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Office	1990-94					0.03
	1985-89				0.09	
	1980-84			0.10		
	1979		0.10			
	1972	0.04				

The p-value for each regression's F-statistic = 0.000.
Data Source: Calculations by authors.

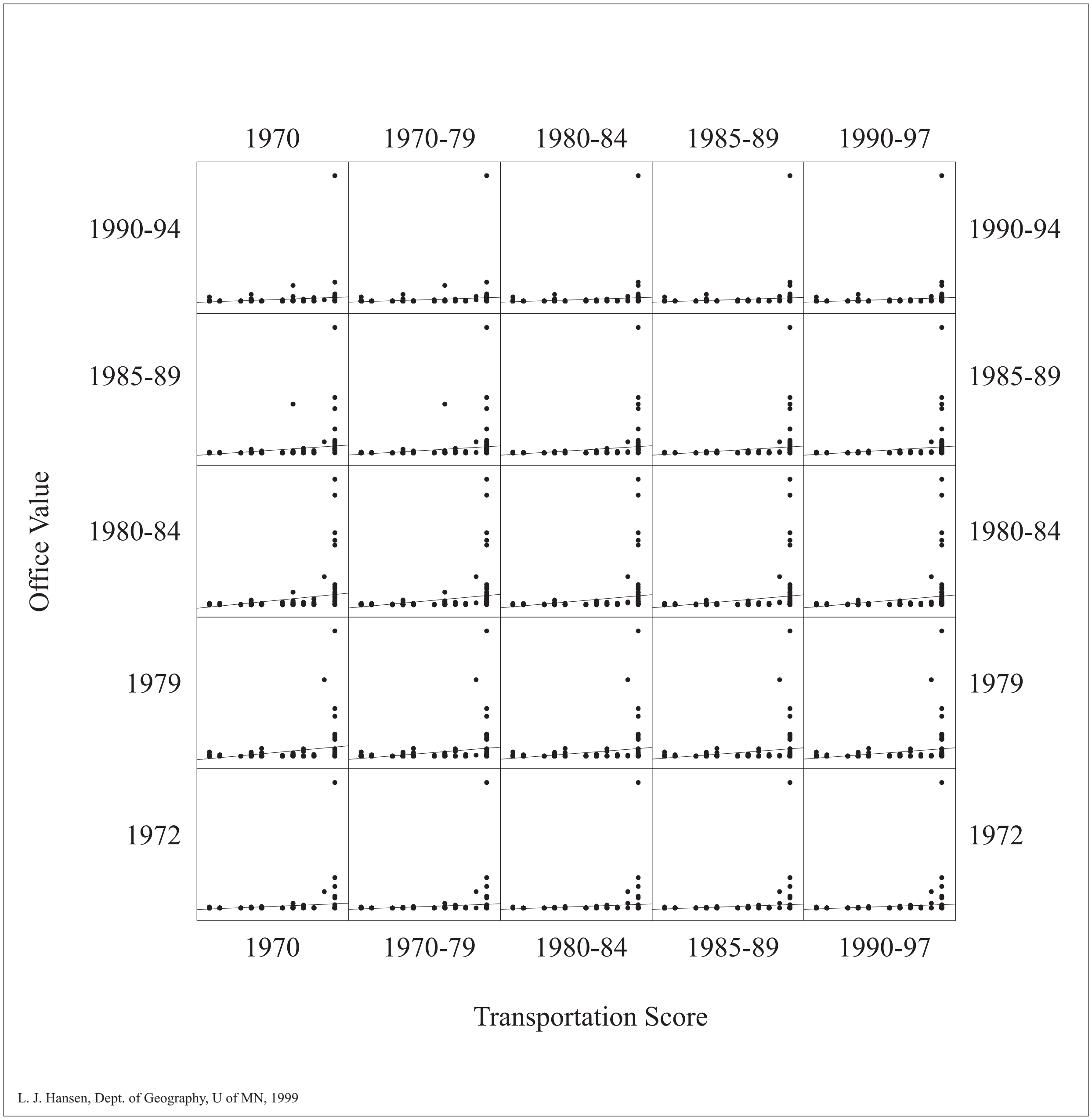


Figure 5.1. Scatterplot Matrix Showing Relationship between Transportation and Standardized Commercial Value, by Time Period, 1970–1997.
Data Source: U.S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file.

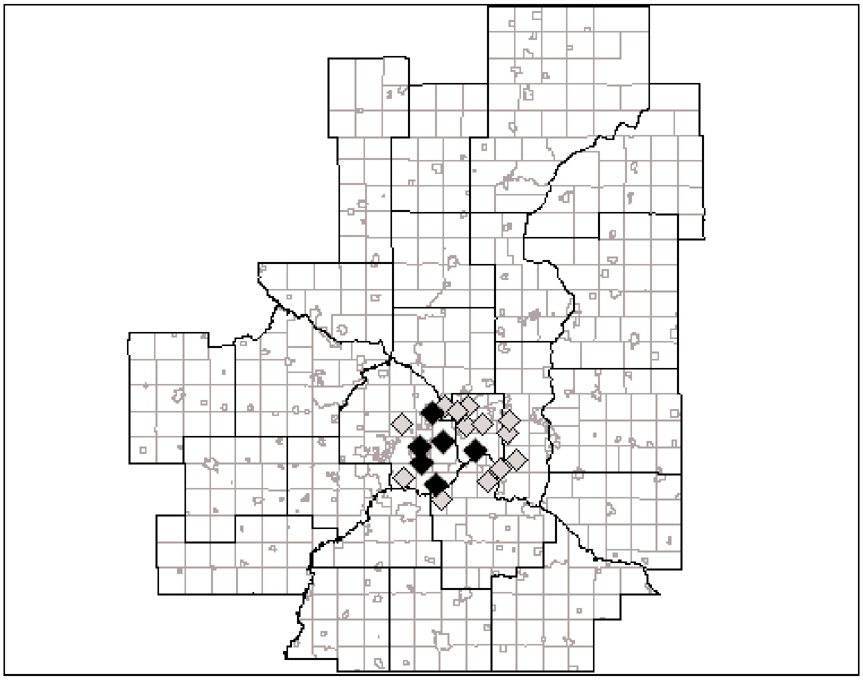
ning, expansion, and building anticipated development while at the same time it responded to demand created by earlier commercial and office development.

The coefficient of determination (r^2) reports the proportion of the variation in value of permitted office development among MCDs that is accounted for or explained by variations in MCD transportation scores as a result of a simple linear regression (Table 5.3). This coefficient varied between 0.00 and 0.15 in the case of residential development (Table 2.3), between 0.05 and 0.09 in industrial development (Table 3.3), and from 0.01 to 0.18 in commercial development (Table 4.3). In the office development case, the regression of office development on transportation score produced similarly low coefficients of determination-ranging from 0.03 to 0.10 (Table 5.3). The results are statistically significant, but peak values in the late 1970s and early 1980s are unimpressive. They imply that the quality of highway transportation infrastructure reached its peak level of influence on office development activity in the 1980s, then gave way sharply in the 1990s to other factors and variables that varied from MCD to MCD.

Residual Unexplained Variations in Value of New Office Construction Permits

"**Transportation scores**" report the degree to which MCDs are served by high-capacity, high-speed highways. "**Office permit values**" is our measure of new office construction volume authorized by building permits. This measure is not standardized by population density or the availability of vacant land. The previous section noted that only a small amount of the variation in office construction among MCDs is accounted for by transportation scores, so most of the unexplained or "residual" variation must be the result of MCD features other than highway transportation infrastructure. Just as in the case of the other three types of development, this residual unexplained variation can be distributed to MCDs using a simple linear regression model that calculates (1) the total value of office permits that might have been expected given an MCD's transportation score (i.e., a predicted value), and comparing this prediction with (2) the value of new office development that was actually authorized and presumably built. This procedure allows us to ascertain which MCDs were over-predicted and those that were under-predicted. Mapping the residuals can often provide clues about what additional factors account for differences between predictions and what actually happened.

In each of the five development eras, office construction is almost exclusively concentrated within the vicinity of the core cities and close-in suburbs, but as we already observed the transportation score is a poor predictor of precisely where office construction will occur. In 1972, six cities, headed by St. Paul, Bloomington and Minneapolis, received values of office construction far beyond predicted levels (Fig. 5.2), while cities with identical transportation scores such



MCD	Transportation Score	Office Value ($)	Predicted Office Value ($)	Studentized Residual
St. Paul	12	29,082,106	934,603	52.8
Bloomington	12	7,044,451	934,603	3.8
Minneapolis	12	4,995,957	934,603	2.5
Edina	11	3,783,300	835,829	1.8
Brooklyn Center	12	2,759,235	934,603	1.1
St. Louis Park	12	2,330,000	934,603	0.8
New Brighton	12	0	934,603	(0.6)
Shoreview	12	0	934,603	(0.6)
Little Canada	12	0	934,603	(0.6)
Woodbury	12	0	934,603	(0.6)
Newport	12	0	934,603	(0.6)
Pine Springs	12	0	934,603	(0.6)
Eden Prairie	12	0	934,603	(0.6)
Inver Grove Heights	12	0	934,603	(0.6)
Arden Hills	12	0	934,603	(0.6)
Burnsville	12	0	934,603	(0.6)
Plymouth	12	11,520	934,603	(0.6)
Roseville	12	50,000	934,603	(0.5)
Fridley	12	58,463	934,603	(0.5)
Oakdale	12	63,164	934,603	(0.5)

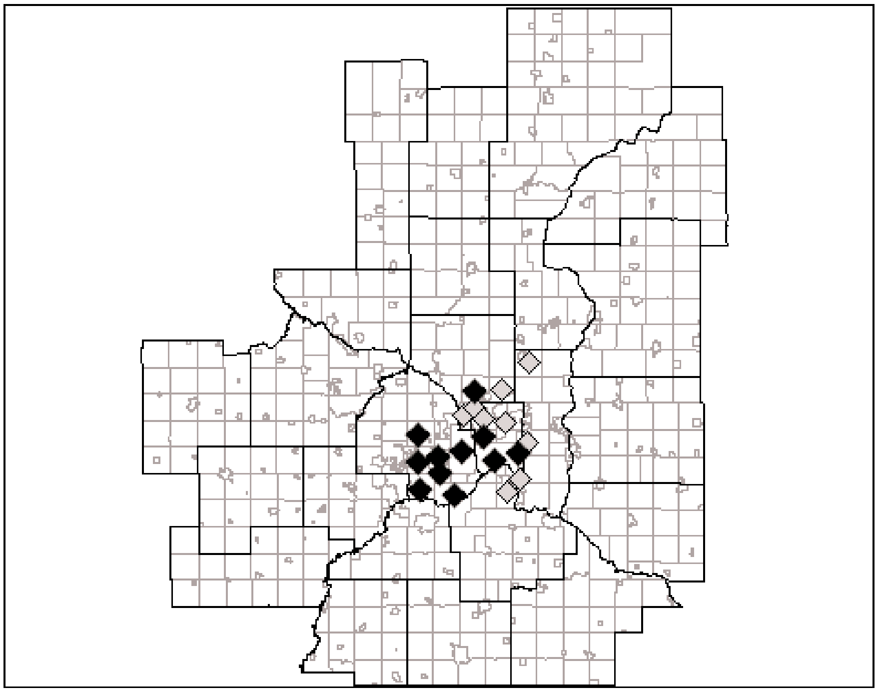
Figure 5.2. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1972. Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

as New Brighton, Shoreview, and Woodbury were under-predicted. To be sure, office buildings, like industrial facilities and commercial structures, are “lumpy”—differing substantially in size, complexity and value. A single skyscraper in downtown Minneapolis will cost many millions of dollars, while a modest office building elsewhere may cost no more than the price of a single house.

In 1979, five of the six cities that were under-predicted in the early 1970s continued to receive far higher values of office development than transportation scores would have predicted (Fig. 5.3). In the same year, Arden Hills, Fridley, Newport, Oakdale, and Inver Grove Heights remain on the list of over-predicted MCDs. What is notable, though, is the conspicuous clustering of under-predicted MCDs west and south of Minneapolis. Those locations received much higher values of office construction than the model predicted.

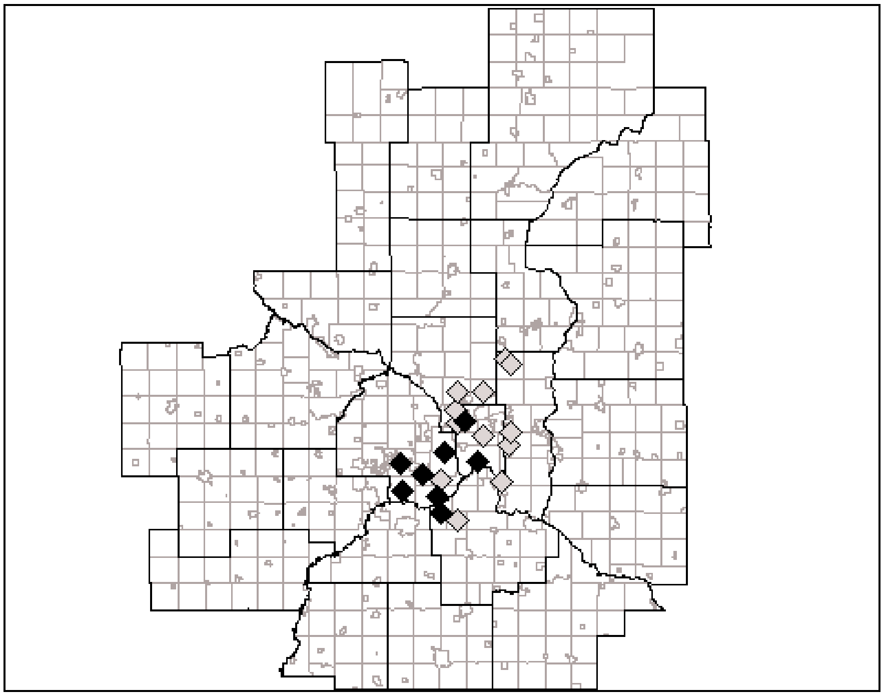
The geographical distribution of large residuals began to disperse from the 1970s pattern during the early 1980s (Fig. 5.4). Under-predicted office construction leaders from earlier eras continue to lead-Minneapolis, Bloomington, Minnetonka, Eden Prairie, St. Paul and Edina. Other suburban MCDs with equally high transportation scores show up in the early 1980s with far lower values of office construction than the regression model predicted. The positive residuals (higher values of office construction than expected based on transportation scores) continue to cluster in the central cities and the western and southern suburbs. The negative residuals (lower values of office construction than expected) are located mainly north and east of Minneapolis and St. Paul.

Essentially the same trends persist and intensify in the late 1980s, with the central cities and suburbs in the southwest quadrant continuing to absorb a disproportionate share of the value of new office construction, beyond what their respective transportation scores predict (Fig. 5.5). Areas south, east and north of St. Paul contain the over-predicted MCDs. To summarize, the maps of residuals for the 1970s and 1980s display a composite of several patterns: consistent under-prediction of office construction value in the central cities and in suburbs immediately west, southwest and south of Minneapolis, and over-prediction mainly in MCDs north, east and south of St. Paul. By the 1990s, the residuals—both positive and negative—are somewhat more dispersed than in earlier eras (Fig. 5.6).



MCD	Transportation Score	Office Value ($)	Predicted Office Value ($)	Studentized Residual
Minneapolis	12	51,628,482	3,347,730	18.3
Edina	11	31,538,675	2,992,820	8.0
St. Paul	12	19,689,000	3,347,730	4.2
St. Louis Park	12	16,513,064	3,347,730	3.4
Maplewood	12	9,177,936	3,347,730	1.5
Eden Prairie	12	9,079,000	3,347,730	1.4
Blaine	12	8,767,677	3,347,730	1.4
Minnetonka	12	7,956,000	3,347,730	1.2
Roseville	12	7,300,000	3,347,730	1.0
Plymouth	12	7,066,000	3,347,730	0.9
Bloomington	12	7,015,823	3,347,730	0.9
Arden Hills	12	0	3,347,730	(0.8)
Lino Lakes	12	0	3,347,730	(0.8)
Vadnais Heights	12	0	3,347,730	(0.8)
Mounds View	12	0	3,347,730	(0.8)
Fridley	12	0	3,347,730	(0.8)
Newport	12	0	3,347,730	(0.8)
Oakdale	12	0	3,347,730	(0.8)
Forest Lake township	12	0	3,347,730	(0.8)
Inver Grove Heights	12	200,000	3,347,730	(0.8)

Figure 5.3. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1979. Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.
Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

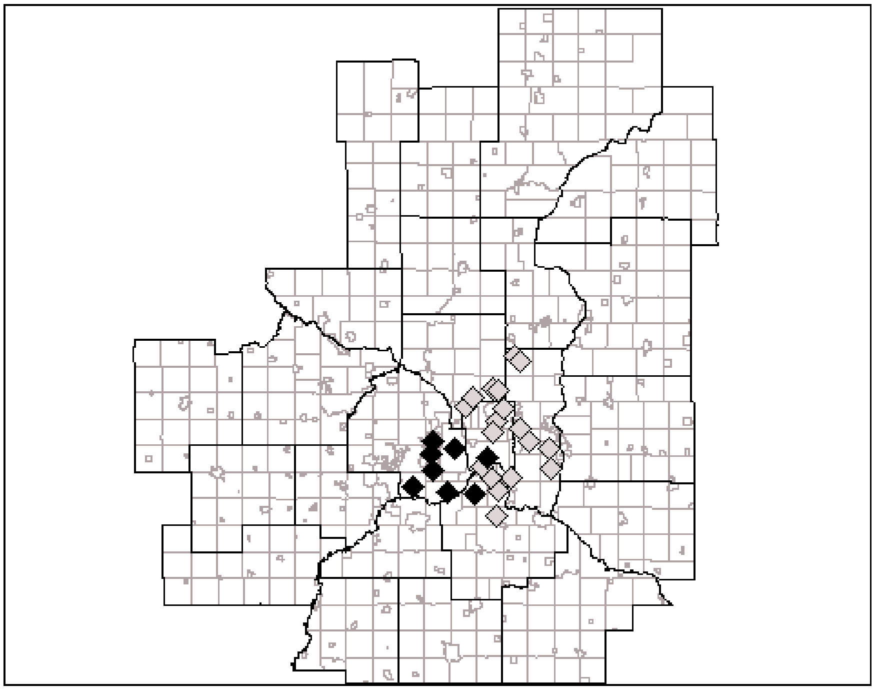


MCD	Transportation Score	Standardized Commercial Value ($)	Predicted Standardized Commercial Value ($)	Studentized Residual
Savage	8	17,427	1,782	8.5
Minnetonka	12	15,943	2,799	7.0
Eden Prairie	12	12,481	2,799	5.0
Shakopee	8	10,661	1,782	4.5
Becker	5	9,025	1,019	4.1
Marshan township	4	8,118	765	3.7
Burnsville	12	10,093	2,799	3.7
Elk River	9	8,350	2,036	3.2
St. Francis	4	6,987	765	3.1
Cedar Mills	0	5,692	(252)	3.0
Bloomington	12	8,342	2,799	2.8
Ham Lake	8	7,347	1,782	2.8
Rosemount	11	7,833	2,545	2.7
Sandstone	7	6,765	1,528	2.6
Maple Grove	12	7,767	2,799	2.5
Eagan	12	7,427	2,799	2.3
Hutchinson	4	5,129	765	2.2
Maplewood	12	7,067	2,799	2.1
Roseville	12	7,064	2,799	2.1
Hugo	4	4,604	765	2.0

Figure 5.4. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1980–84.

Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

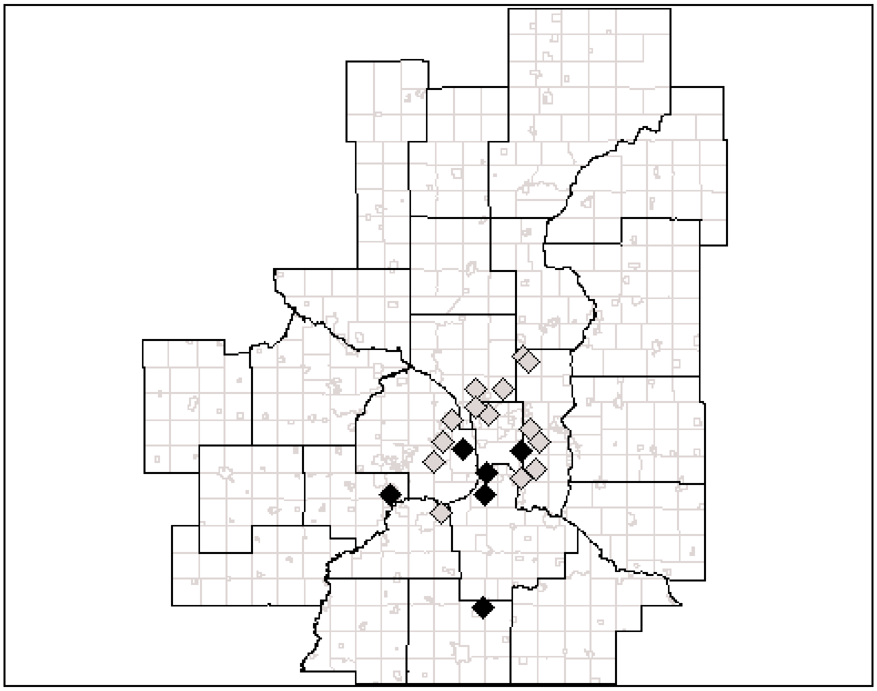


MCD	Transportation Score	Office Value ($)	Predicted Office Value ($)	Studentized Residual
Minneapolis	12	314,951,312	15,049,400	26.7
Bloomington	12	139,043,083	15,049,400	6.9
Eagan	12	122,404,000	15,049,400	5.9
St. Paul	12	111,016,335	15,049,400	5.2
Eden Prairie	12	59,914,000	15,049,400	2.4
Golden Valley	12	31,653,722	15,049,400	0.9
Forest Lake township	12	0	15,049,400	(0.8)
Pine Springs	12	0	15,049,400	(0.8)
Mounds View	12	116,203	15,049,400	(0.8)
Lino Lakes	12	283,000	15,049,400	(0.8)
Forest Lake	12	313,500	15,049,400	(0.8)
Little Canada	12	516,005	15,049,400	(0.8)
Newport	12	674,000	15,049,400	(0.8)
Vadnais Heights	12	800,000	15,049,400	(0.7)
Edina	11	27,601,080	13,469,800	0.7
Inver Grove Heights	12	1,429,000	15,049,400	(0.7)
Lake Elmo	12	1,747,704	15,049,400	(0.7)
Rosemount	11	633,332	13,469,800	(0.7)
St. Louis Park	12	27,407,981	15,049,400	0.6
(seven tied for 20th)	10	0	11,890,300	(0.6)

Figure 5.5. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1985–89.

Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.



MCD	Transportation Score	Office Value ($)	Predicted Office Value ($)	Studentized Residual
Minneapolis	12	350,475,800	8,856,560	85.5
Maplewood	12	52,983,774	8,856,560	2.5
Eagan	12	43,632,000	8,856,560	1.9
Chaska	4	18,763,893	1,550,820	0.9
Northfield	0	11,297,784	(2,102,050)	0.7
Mendota Heights	12	19,879,409	8,856,560	0.6
Lake Elmo	12	0	8,856,560	(0.5)
Pine Springs	12	0	8,856,560	(0.5)
Forest Lake township	12	0	8,856,560	(0.5)
Mounds View	12	0	8,856,560	(0.5)
Woodbury	12	0	8,856,560	(0.5)
Lino Lakes	12	262,000	8,856,560	(0.5)
Newport	12	674,334	8,856,560	(0.5)
Hopkins	11	10,000	7,943,340	(0.4)
Brooklyn Center	12	1,079,247	8,856,560	(0.4)
Shoreview	12	1,162,000	8,856,560	(0.4)
Blaine	12	1,231,953	8,856,560	(0.4)
Forest Lake	12	1,260,500	8,856,560	(0.4)
Golden Valley	12	1,300,000	8,856,560	(0.4)
Savage	11	500,000	7,943,340	(0.4)

Figure 5.6. Top Twenty Outliers, Standardized Industrial Value vs. Transportation, 1990–94.

Negative outliers are shown in gray on the map. Outliers are listed in order of magnitude of residual from expected value. Negative values appear in parentheses.

Data Source: U.S. Department of Commerce, Bureau of the Census, Residential Building Permits, tape file. Calculations by authors.

Leads and Lags between Transportation Scores and Office Construction

Most MCDs in the study area reported issuing no office development building permits. We know this because the median value of office permits was zero in each time period (Table 5.1). As we try to explain the variation in office construction permits (the dependent variable) with reference to variations in highway transportation scores (the independent variable), the fact that the statistical distribution of office construction permits in each era is highly skewed with mostly zero values distorts our estimates of the correlation between the two variables. As before, the way to remove some of the distorting effects of the highly skewed distribution of value of office building permits is to transform that distribution. In the case of office values, the form of the skewness suggested that the most appropriate transformation of the dependent variable is the square root of an MCD's office permit value.

The correlation analysis using the square root of office value concluded that office development apparently both leads and lags improvements to highway transportation infrastructure. The correlations between transportation scores and the square root of the value of office construction are high in each era, rising steadily from 0.35 in the early 1970s to a peak of 0.50 in the late 1980s before dropping in the 1990s (Table 5.4). This series of correlation coefficients tells us that the linkage between transportation scores and office permit values peaked in the late 1980s, then dropped, presumably because other factors began overtaking highway infrastructure in relative influence on office location, or alternatively that office locations began giving way to other factors in influencing the location of highway improvements. The fact that the correlations above and to the left of the diagonal on average are notably higher than those below and to the right are consistent with the idea that early transportation scores had more influence on later office construction than the other way around. Leads and lags both appear robust, but transportation scores seem to lead later office construction rather than the reverse.

Effects of MCD Location on Rates of Office Construction

Correlation analysis concluded that office development apparently both lags and leads improvements to highway transportation infrastructure. Maps of residuals from the regression of value of office construction on transportation scores for each of the five development eras revealed a composite of several geographical patterns: consistent under-prediction of office construction in Minneapolis, St. Paul, and suburbs immediately west, southwest and south of Minneapolis; and over-prediction for MCDs mainly north, east and south of St. Paul.

Table 5.4. Correlation Values of the Relationship between Transportation and Square Root of Office Value, by Time Period, 1970 to 1997.

		Transportation				
		1970	1970-79	1980-84	1985-89	1990-97
Office	1990-94	0.42	0.41	0.42	0.41	*0.41*
	1985-89	0.51	0.49	0.51	*0.50*	0.50
	1980-84	0.50	0.48	*0.49*	0.48	0.48
	1979	0.50	*0.47*	0.46	0.45	0.45
	1972	*0.35*	0.34	0.34	0.34	0.33

Values are Pearson's correlation coefficients, r .
Data Source: Calculations by authors.

Table 5.5. Coefficient of Determination Values (r^2) from Multiple Regression Analysis of the Relationship of Transportation and Location to Square Root of Office Value, by Time Period, 1970 to 1997.

		Transportation and Location				
		1970	1970-79	1980-84	1985-89	1990-97
Office	1990-94					0.41
	1985-89				0.59	
	1980-84			0.50		
	1979		0.48			
	1972	0.24				

The p-value for each regression's F-statistic = 0.000.
There is no data for Locations 16, 17, and 18 in 1979.
The cases of Minneapolis and St. Paul were excluded from the analyses in 1972 and 1990-94 because of their high values of Cook's Distance (D_i) = 3.4 and 6.0, respectively.
At a level of significance of 0.10, all Location variables proved significant in the analyses except in 1972 and 1990-94 when only Location 2 proved significant.
Data Source: Calculations by authors.

Examination of the maps of residuals suggests that the location of an MCD within the 24-county study area may also exercise influence on rates of office construction, an influence that is somewhat independent of MCD transportation scores. We carried out a regression analysis for each of the five development eras adding location of MCDs within the study area as an additional explanatory variable. The square root of office value (dependent variable) was then regressed against transportation score and location within the study area.

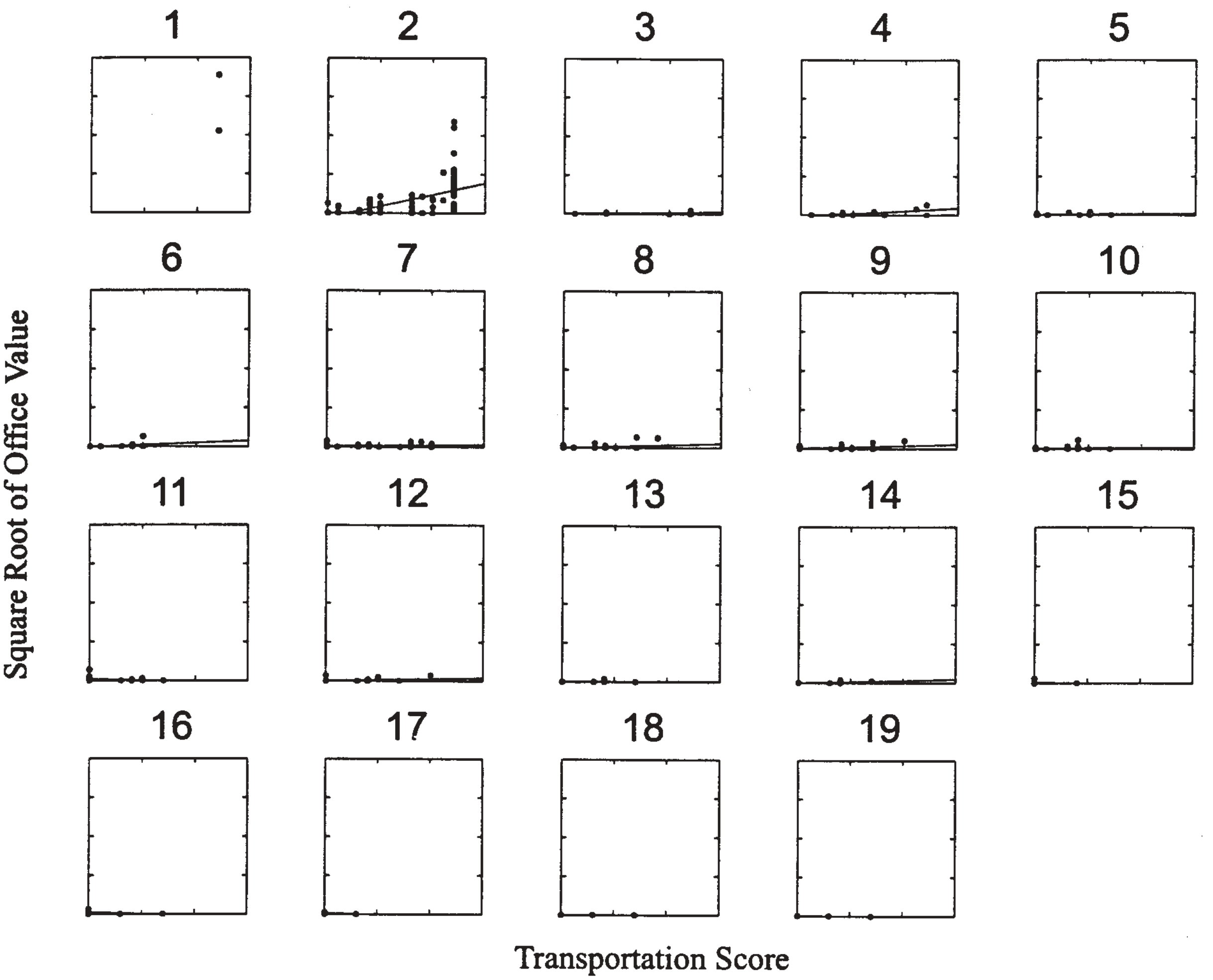
The coefficients of determination (r^2) suggest that transportation scores along with MCD location together played important roles in accounting for variations in office permit values among MCDs. The coefficient was smallest in the early 1970s at 0.24, rose to a peak value of 0.59 in the late 1980s, then declined a bit to 0.41 in the 1990s. The fact that the explanatory power of transportation scores and location diminished in the 1990s implies that the roles of transportation as measured by the transportation scores (0–12), and of location as reported by the categorical data (1–19), have been eroded by the influence of other variables as in the case of industrial and commercial development.

To obtain a more refined sense of the importance of transportation and location in explaining the geographical patterning of office construction, regressions were plotted separately for each of the 19 locations for 1985–89; this was the era when the coefficient of determination from the regression including location reached its maximum (Fig. 5.7). The plots resemble those for commercial and industrial development, with Location 2, the urbanized and urbanizing area containing the 88 MCDs outside the two central cities but within the MUSA line, containing most of the action. The other 18 locations had too little office construction to yield reliable trends.

Summary and Conclusions

Specific questions addressed in this chapter cover the following issues:

- Do highways and highway improvements serving an MCD stimulate office construction at that place? Findings: transportation scores for MCDs in each of the five eras were significantly correlated with the value of office permits issued by MCDs during the same era. The correlations are highest in the late 1970s and early 1980s (values of 0.32); lowest in the 1990s (value of 0.18).
- Does office construction in an MCD appear to promote highway improvements to serve that place? Findings: the general answer appears to be “yes” once again. Office construction in each era is significantly correlated with later transportation improvements.
- Is the relationship circular—as seems likely? Findings: transportation scores for earlier



L. J. Hansen, Dept. of Geography, U of MN, 1999

Figure 5.7. Plots Showing Relationship between Transportation and Square Root of Office Value, for Each Location Variable, 1985–89.

Data Source: U.S. Department of Commerce, Bureau of the Census, Non-Residential Building Permits, tape file. Calculations by authors.

eras are significantly correlated with office development in later eras, and vice versa. However, transportation scores for 1970 and office developments of the end of the 1970s and the early 1980s have the highest correlations of any of the pairings (values of 0.35).

- Do statistical measures of lead-lag relationships remain constant through time? Findings: no, they vary—correlation coefficients relating office construction values and transportation scores are lowest for construction in the early 1970s and in the 1990s, and highest for office construction values from the end of the 1970s through the 1980s. The coefficient of determination (r^2) is lowest in the 1970s with a value of 0.03, and highest in the late 1970s and early 1980s with a value of 0.10. When the square root of office value from each era is correlated with transportation scores of each era, earlier transportation scores have on average higher correlations with later construction values; early office values have on average lower correlations with later transportation scores. This finding suggests that transportation infrastructure leads office development slightly more than the reverse.
- What happens to levels of statistical explanation when location is considered? Findings: adding locations to transportation scores to account for variations in the square root of office values raises the r^2 to levels as high as 0.59 in 1985–89. The r^2 value was lowest in the early 1970s, then peaked in the late 1980s before dropping in the 1990s. Just as in the cases of residential, industrial, and commercial development, as the highway system improved throughout the study area, transportation scores and locations within the 24-county study area declined in importance in explaining office development location in the 1990s as other factors rose in importance.

Chapter 6

Summary and Conclusions

This study responds to the questions: how are improvements in highway transportation and patterns of land development in suburban and exurban areas associated? Do road improvements encourage land development? Or is it the other way around? Do the cause-effect relationships that link the two remain constant through the decades? Or have they changed over the period from 1970 to the present?

Specifically, we asked:

- Do highways and highway improvements serving an MCD stimulate development at that place?
- Does land development in an MCD promote highway improvements to serve that place?
- Is the relationship circular—as seems likely?
- Do statistical measures of lead-lag relationships remain constant through time?
- Do statistical measures of lead-lag relationships remain constant across locations?
- Do the statistical relationships differ depending on the type of development?

To answer these questions, we used building permit data for four kinds of development—residential, industrial, commercial, and office—for 631 minor civil divisions within a 24-county commute zone surrounding the Minneapolis-St. Paul metropolitan area, and related development to highway access and MCD location for the period 1970 to 1997.

Residential Development

- Transportation scores in the 1970s and early 1980s were significantly correlated with residential construction during the 1980s, with correlation values ranging between 0.34 and 0.38. Residential construction rates in the 1990s were essentially uncorrelated with MCD transportation scores.
- Housing construction in the 1980s is significantly correlated with transportation scores of the late 1980s and 1990s, with correlation values ranging between 0.36 and 0.39.
- For the 1980s, the relationship between highway transportation scores and housing construction appears to be somewhat circular; correlations between construction rates and

transportation scores never exceed 0.39, or 0.43 using log of construction rates.

- The effects of transportation on residential development seem to be greatest for transportation scores of the 1970s and construction of the 1980s; and for housing construction of the 1980s and its effects on transportation scores of the 1990s. Coefficients of determination range from 0.0 in the 1990s to 0.15 in the early 1980s.
- It is hard to tell whether statistical measures of lead-lag relationships remain constant across locations because there are too few cases at many of the 19 locations for reliable estimates. For the locations close to the metropolitan core, it is plain that the statistical relationships vary from place to place. Adding location to the regression model raises the coefficients of determination to values between 0.15 in the 1990s and 0.25 in the 1980s.

Even when construction data distributions are appropriately transformed, and MCD location as well as transportation score is taken into account, only about a fourth of the variation in MCD housing construction rates is accounted for. The remaining 75 percent of unexplained variation is due to differences among MCDs that have not been taken into account.

Industrial Development

- Transportation scores in each of the five eras were significantly correlated with industrial permit activity. The correlation coefficients were lower than in the case of housing, but varied only modestly from one era to another.
- Industrial construction in an MCD also appears to promote highway improvements to serve that place. Industrial construction in each era is significantly correlated with later transportation improvements with coefficients varying between 0.22 and 0.29.
- The relationship between transportation scores and industrial development appears to be circular. Transportation scores for earlier eras are correlated with industrial development in later eras, with correlations ranging between 0.22 and 0.30.
- The effects of transportation on development for the five eras seem to be fairly consistent through time, with correlations varying between 0.22 and 0.29; and coefficients of determination (r^2) varying from 0.05 to 0.09. These values are statistically significant, but obviously transportation scores do not explain much. When the dependent variable is transformed and the square root of standardized industrial value is used, the correlations rise to a range of 0.37–0.46 for transportation and development in simultaneous eras, and are approximately the same for lead-lag and lag-lead correlations.
- Adding location to transportation score as an additional explanatory variable to account for variations in the square root of standardized industrial values raises the coefficients of determination to levels between 0.29 and 0.69. The r^2 values rose from 0.53 in the early 1970s, reached a peak at the end of the 1970s, then dropped to lower levels in the 1990s. Evidently as the highway system improved, transportation score and location within the

24-county study area meant less as other factors rose in importance.

Commercial Development

- Transportation scores in each of the five time periods were significantly correlated with commercial permit values from the same era. The correlations are highest for the 1980s, reaching a value of 0.42 in the early 1980s.
- Commercial construction in an MCD appears to promote highway improvements to serve that place. Commercial construction in each era is significantly correlated with later transportation improvements, with correlations highest for the 1980s.
- Again, the statistical relationship appears to be circular. Transportation scores for earlier eras are correlated with commercial development in later eras, and vice versa. The commercial developments of the 1980s are most strongly correlated with transportation scores before, during, and following the 1980s, with values ranging from 0.37 to 0.43.
- Statistical measures of lead-lag relationships do not remain constant through time. They vary—correlation coefficients relating commercial construction values and transportation scores are lowest for construction in the late 1970s and in the 1990s, and highest for commercial construction values of the 1980s. The coefficients of determination (r^2) reach their highest value of 0.18 in the early 1980s. When the log of standardized commercial values from each era are correlated with transportation scores of each era, earlier construction has high correlations with later transportation scores (correlation values ranging from 0.40 to 0.55); early transportation scores have lower correlations with later construction values (correlation values ranging from 0.34 to 0.49). This finding suggests that the commercial construction leads transportation improvements slightly more than the reverse.
- Adding locations to transportation scores to account for variations in the log of standardized commercial values raises the coefficient of determination (r^2) to levels as high as 0.37. The r^2 value was highest in the early 1970s, then dropped to 0.19 in the 1990s. Just as in the cases of both residential development and industrial development, as the highway system improved, transportation scores and location within the 24-county study area declined in importance in the 1990s as other factors rose in importance.

Office Development

- Transportation scores for MCDs in each of the five eras were significantly correlated with the value of office permits issued by MCDs during the same era. The correlations are highest in the late 1970s and early 1980s (values of 0.32); lowest in the 1990s (value of 0.18).
- Office construction in an MCD appears to promote highway improvements to serve that place. Office construction in each era is significantly correlated with later transportation improvements.

- Again, the relationship appears to be circular. Transportation scores for earlier eras are significantly correlated with office development in later eras, and vice versa. However, transportation scores for 1970 and office developments of the end of the 1970s and the early 1980s have the highest correlations of any of the pairings (values of 0.35).
- Statistical measures of lead-lag relationships do not remain constant through time. Correlation coefficients relating office construction values and transportation scores are lowest for construction in the early 1970s and in the 1990s, and highest for office construction values from the end of the 1970s through the 1980s. The coefficient of determination (r^2) is lowest in the 1990s with a value of 0.03, and highest in the late 1970s and early 1980s with a value of 0.10. When the square root of office value from each era is correlated with transportation scores of each era, earlier transportation scores have on average higher correlations with later construction values; early office values have on average lower correlations with later transportation scores. This finding suggests that transportation infrastructure leads office development slightly more than the reverse, an opposite finding than that for commercial development.
- Adding locations to transportation scores to account for variations in the square root of office values raises the r^2 to levels as high as 0.59 in 1985–89. The r^2 value was lowest in the early 1970s, then peaked in the late 1980s before dropping in the 1990s. Just as in the cases of residential, industrial, and commercial development, as the highway system improved throughout the study area, transportation scores and locations within the 24-county study area declined in importance in explaining office development location in the 1990s as other factors rose in importance.

Finally, in comparing the multiple regression model across the four types of development, the coefficient of determination (r^2) value reaches a peak of 0.25 in the 1980s for housing development (Table 2.5); industrial development reaches a peak of 0.69 in the late 1970s (Table 3.5); commercial development reaches a peak of 0.37 in the early 1970s (Table 4.5); and office development peaks at 0.59 in the late 1980s (Table 5.5).

In conclusion we ask: what have we learned—if anything—to guide us in the future regarding the relationships between highways and land development? Although statistical relationships describing correlations of leads, lags, and contemporaneous change were found to be highly significant, the measures of those relationships were seldom constant. They changed from one time period to the next, from one type of development to another, and from one location to another within specific time periods.

Another way to explore these matters for additional insight would be to shift the geographical scale of the analysis and look inside specific cities, towns and townships to examine local land use planning practice, along with locational decision making on the part of households, land speculators, developers, builders, and their clients. Further insight might also be gained by exploring the decision criteria used by the financial community in allocating capital for land development. Yet another refinement of this study would examine features of the landscape itself at various scales and evaluate its suitability for different kinds of development, which may or may not be considered within local land use planning practice.

Our correlations were robust, but there remains a substantial amount of unexplained variation that goes unaccounted for by the limited number of variables whose influence we examined. There is much more to the story, and later studies in this series tackle some of these possibilities.