Time-Series Maps for the Projection of Land-Use Patterns

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TIME-SERIES mapping of quantified land-use data has been used for many years in historical geography to study the evolution of present patterns from the past. The procedure is extended here to embrace extrapolation from the past through the present into the future. The procedure includes four steps: (1) quantification and mapping of land-use data at time intervals over a number of years; (2) measurement of change in both the intensity and location of major uses; (3) search for regularities in both locational characteristics of major land uses and the rate, direction, and magnitude of change, and (4) extrapolation of both intensity and location of major land uses, on the basis of past regularities, into the near future.

This paper presents two examples of the procedure which has aided the projection

Figure 1. Number of dwelling units per quarter square mile, 1900.
of future land-use patterns for highway planning purposes in the Minneapolis-St. Paul metropolitan area. The studies discussed use time-series maps. The examples are intended to serve two purposes. First, they illustrate the procedures which have been used. Second, they provide the basis for a brief discussion of the applied and theoretical value and the limitations of studies of this type.

RESIDENTIAL EXPANSION

A time-series of maps was used in preparing a 1980 forecast of residential growth for the Twin Cities Area Transportation Study (TCATS), carried out by the Minnesota Department of Highways in cooperation with the U.S. Bureau of Public Roads. The dwelling unit forecast data were subsequently converted into trip-end data and used in traffic forecasting and assignment. It should be understood that as yet there exists no mechanical procedure which assures a dwelling unit forecast suitable for detailed traffic forecasting needs. The exercise of considerable subjective judgment is necessary. However, it is essential that the forecaster has the best possible understanding of the metropolitan area in which he is working. Further, he needs as much quantitative data as possible to implement his understanding of the nature of metropolitan growth and to back up whatever subjective judgments are necessary. The time-series map technique is useful in filling those needs.

The basic map series used in this analysis showed the number of dwelling units by quarter section for the years 1900, 1915, 1945, 1951, and 1958. Four of the maps are reproduced here (Figures 1-4). The study area consisted of about 3,600 quarter sections. Sources used for the historical series were insurance maps, U.S. Geological

![Figure 2. Number of dwelling units per quarter square mile, 1945.](image-url)
Survey sheets, aerial photographs, census material, and land-use surveys. Isolines were drawn to outline the density classes of 0.50, 50-125, 125-250, 250-500, 500-1,000, and 1,000-2,000 dwelling units per quarter section. From these basic maps, a second series of maps showed the change in dwelling unit density per quarter section during each time interval (Fig. 5). A third very useful series showed the "percentage of saturation" for 1945, 1951, and 1958. This map showed the existing number of dwelling units expressed as a percent of the estimated maximum possible number of single-family units, or "saturation" density, by quarter sections. A fourth map group showed the changing positions of individual density isolines for each of the years in the series. These four series of maps provided a detailed, three-dimensional picture of the residential expansion and "filling-in" of the metropolitan area.

Much can be learned about the growth characteristics of an area simply by studying such a set of maps. Four investigations of particular value were carried out.

First, the study area was divided into 45-deg sectors radiating from both the Minneapolis and St. Paul CBD's. Dwelling units added in each sector were totaled for two expansion periods, 1945-51 and 1951-58. The results produced (a) a clear understanding of growth throughout the metropolitan area during the past 15 yr of rapid expansion, (b) measures of persistence of growth in given directions (c) measures of changes in direction of growth, and (d) comparative data needed to explain differences in expansion rates in various directions.

Second, rates of movement of the advancing urban frontier were investigated for the same sectors. To do this, it was assumed that the isoline of 125 dwelling units per quarter section defined the edge of the built-up area. The position of this isoline

Figure 3. Number of dwelling units per quarter square mile, 1958.
was mapped from 1900 through 1958 (Fig. 6), with special attention to the years 1945 through 1958. This map, superimposed on the map of dwelling unit change, indicated the number of dwelling units added between the isolines during each time period. This procedure yielded data on several important characteristics of growth, including (a) absolute rates of movement of the advancing urban frontier, (b) fraction of the total area being added to each sector through growth contiguous to already built-up area, (c) relationships between movement rates and density of new areas (it was found that in both the 1945-51 and 1951-58 the areas where the urban frontier advanced fastest were also the areas which received the highest density of growth), and (d) a measure of the degree of scatter of new growth, by sector. The latter measure was obtained by comparing the number of dwelling units added at the edge of the built-up area with the number added throughout the entire sector. In the fastest-growing sector from 1951 to 1958, it was found that 60 percent of the growth was contiguous to the previously built-up area. In other sectors the figure ranged from 10 to 50 percent.

Third, an investigation of densities of development was carried out. It was well-known that much suburban growth is of low density, but no data were available on just what densities were common or on the locational pattern of different density groups. This study was based directly on the original series of maps of dwelling units. It indicated, for example, that the portion of all dwelling units in density classes under 500 per quarter section rose from 27 percent in 1945 to 34 percent in 1951 and rose again to 41 percent in 1958. Data of this type, and trends the data revealed, were of primary importance in forecasting not only for the total area but for given sectors. The trend toward lower density, for example, is responsible for the sprawling nature of the 1980 map.

Figure 4. Number of dwelling units per quarter square mile, 1980.
The foregoing illustrations represent types of quantified data, from time-series maps, which were of value in forecasting procedures. Because one cannot blindly project past trends, it was considered necessary to attempt to find the reasons for differences in intensity and direction of growth. In the Twin Cities area one of the primary correlatives of rapid, intense growth in a given direction was the presence of a large amount of reasonably level, well-drained land suitable for mass development in middle and lower price ranges. Also, advancing development on such land had the highest suburban density and the highest rate of advance of the urban frontier. The time-series studies showed greater contiguity and less scattering of growth on the flat land and strong persistence of growth rate and direction in the flat land sectors over a 5- to 10-yr period.

Another correlative of rapid expansion in given areas is found in the accessibility characteristics of the areas. Accessibility may be defined in three principal ways:

1. Access to highways, which minimize travel time for relatively long trips within the metropolitan area.
2. Access to major functional areas of the city, especially major employment areas.
3. Time-distance from the Minneapolis CBD. (Although the Twin Cities area has double CBD's there is an observable tendency toward formation of a symmetrical urban complex around the Minneapolis core.)

A third factor found associated with suburban expansion into a given area is simply the location of previous growth. The persistence of primary growth patterns is obvious
and striking. If one had to predict location of growth in the absence of much information, he would guess well to put the predicted growth at the present edge of the built-up area. It is recognized, of course, that this factor is not a determinant of growth characteristics, as are land-type and access.

The foregoing information, derived from time-series of maps, had direct value in forecasting. The information and the technique have also aided in the formation of hypotheses regarding urban growth. The hypotheses have played an important part in attempts to synthesize a satisfactory dwelling unit forecasting model, and that is probably their more important use in the long run.

COMMERCIAL--INDUSTRIAL GROWTH

The second illustration is a study of two major circumferential highways on the western edge of the Twin Cities (2). Both routes are shown in Figure 7. The two highways include existing Minnesota State Highway 100 and proposed Interstate Route 494. The existing highway was opened shortly before 1940. The proposed route will open about 1965. Both will serve as urban distributors and circumferentials. The problem was to project the probable pattern and intensity of major commercial-industrial land uses on the new Route 494.

The first step was to define two study strips each 1 mi in width centered on each highway. Next, the analogy of the two strips was established. Both will have been constructed to the highest standards used at the time of their opening; both are intersected by the same major radial highways and rail lines; both will have been located along the western frontier of urban expansion at the time of their opening (Fig. 8).
Observers recorded and mapped the land area used by every non-residential establishment in the Highway 100 study strip for six different years from 1940 through 1959. The data were taken from aerial photographs and plat maps. The total of about 250 establishments were grouped into three categories. Two groups of retail and service establishments were recognized:

1. Shopping center uses, including grocery and drug stores, clothing stores, radio repair shops, for example.
2. Highway-oriented and urban-arterial uses, including auto sales, filling stations, drive-ins, lumber yards, and other similar uses (1).

Two other groups recognized were:

3. Warehousing.
4. Manufacturing uses, including associated office areas.

The establishments were then mapped for each year according to land-use category and land area. Figure 9 shows the patterns for the first and latest years of the series—1940 and 1959. Intermediate maps in the series show the details of evolution of the present-day pattern.

From the maps it was possible to determine the trends in site, locational character

Figure 7. The present and projected Belt Line highways around the Minneapolis-St. Paul metropolitan area. Heavy solid lines mark the position of T.H. 100. Heavy dashed lines mark the Interstate Highway routes. The "western quadrant," to which this study refers, is indicated by fine stippling.
Figure 8. The similar positions of the old and new Belt Lines with reference to the advancing urban frontier. Heavy solid lines indicate generalized western boundaries of 500 or more dwelling units per square mile at successive times.
Figure 9. Development of commercial-industrial land uses, T. H. 100 study strip, 1940-59.
and land requirements for each type of use. Site requirements had remained practically constant. Commercial and industrial uses have adhered to level or gently-rolling, well-drained land. These site characteristics were quantified so that similar sites could be identified along Route 494.

Four important locational characteristics were identified, as follows:

1. The highway-oriented (including urban-arterial) retail and service uses along Highway 100 show a close relationship to volume of traffic; that is, the only use class which appeared to be traffic-related. Figure 10 shows how it differs in its locational characteristics from the other major use classes.

2. Shopping center-type uses show a unique and quasi-constant association with the density of residential dwelling units. The degree of association is indicated by Figure 11.

3. Manufacturing and warehousing development were found to vary with distance by fastest highway from the Minneapolis CBD. The relationship between acreage in those uses and distance from the CBD in six major industrial concentrations is shown in Figure 12. The one area which appears anomalous on the graph is currently developing very rapidly. The time-series maps revealed that none of these relationships between particular uses and particular types of locations appeared full-blown at the

Figure 10. Commercial-industrial land uses related to traffic volume for 7 different segments comprising the T. H. 100 study strip. The dashed line on each graph has a slope of 1. Only the highway-oriented retail and service uses appear to show a close relationship to traffic volume.
Figure 11. Shopping center-type retail and service uses along T. H. 100, 1945-1959. Shaded area indicates dwelling unit density greater than 125 per ¼ square mile.
beginning of the 20-yr period. Instead, they evolved over time into the orderly pattern which they have today.

4. It was observed that all of the major uses, regardless of whether they were oriented toward highway traffic, neighborhood residential growth, or the CBD, showed certain locational affinities within the study strip. Virtually all establishments lay within 2,500 ft of a major highway intersection; and virtually all warehousing and manufacturing establishments lay within 1,000 ft of both a major highway and a rail line.

Regularities and trends noted along Highway 100 permitted the projection of land uses along the analogous proposed Route 494. Ratios were computed to relate land requirements to traffic volume for the highway-oriented uses. These ratios made it possible to project acreage of highway-oriented uses on the basis of traffic projections for various segments of proposed Route 494. Ratios were also computed to relate shopping center types of land use to dwelling-unit density. Thus acreage of shopping center uses could be projected for various segments of Route 494 on the basis of projected residential growth (Fig. 4).

The projection of manufacturing and warehousing land requirements for Route 494 was somewhat more complex. Trends in land development for these two uses along Highway 100 were assumed to reflect a general demand for warehousing and industrial land along any major western circumferential highway in the metropolitan area. It was assumed that this general condition has been met historically by Highway 100 and will be met also in the near future by Route 494. Upper and lower ceiling were defined for growth of warehousing and manufacturing development in the Highway 100 study strip. A lower ceiling was determined by the remaining amount of level or gently-rolling, well-drained land within 1,000 ft of trackage and major highway frontage. An upper ceiling was determined by the additional remaining level, well-drained land within 2,500 ft of a major highway intersection. The available land below the first ceiling was assumed to be certain of development at the rate now prevailing in the Highway 100 study strip. It was assumed that the land between the lower and upper ceiling is marginal; it will be developed eventually but at a diminishing rate.

Figure 13 shows the resulting projection of demand for warehousing and manufacturing land in the Highway 100 study strip. The trend from 1940 through 1959 was projected

Figure 12. The relationship between industrial development and distance from the Minneapolis CBD for the six major highway-rail trackage locations in the T.H. 100 study strip, 1959.
in the form of a growth curve. It was assumed that, once the lower ceiling was reached, the development rate would decelerate at the same rate at which it accelerated in the early years after 1940. The recent, maximum rate of industrial development in the late 1950's was taken as the potential demand for industrial land along a western circumferential highway. There is a widening difference between projected development on Highway 100 and projected demand for land on a western circumferential. That difference was considered to be "surplus" demand transferable from Highway 100 to Route 494. It is apparent that the validity of this projection depends heavily on the assumption that the so-called "growth curve" plotted and projected for Highway 100 is representative of some general behavior of real estate development in cases of this nature. Much more study is needed in support of this assumption.

Through the use of procedures described, projections were made for the total acreage

Figure 13. Manufacturing and warehousing highway 100 numbers on face of grid indicate acres. Solid curve represents rate of observed development 1940 to 1959; dashed curves represent projections. Upper dashed curve represents projected demand for industrial land in a western circumferential highway location. Shaded areas represent excess of demand over amount of land supplied from the Highway 100 strip. Dash-dot lines represent limits of supply of first-class and marginal land.
of land developed in each major commercial-industrial use along proposed Route 494 within 15 yr after the opening date. The probable geographical distribution of the acreage was also projected on the basis of locational characteristics observed in the development along Highway 100. The distribution was shown by means of a prognostic map.

CONCLUSIONS

The use of time-series maps for land-use projection is an adaptation of the method used in the biological study of the morphology of growth or in the meteorological analysis of a time-series of weather maps and the development of a prognostic chart. The maps provide a facsimile of observed changes in land uses associated with growth, decline, and changing relative location. The procedure simplified land use forecasting problems by (a) seeking the key to the near future in the recent past and (b) basing the forecast on empirical data from the same geographical and historical context for which the forecast is to be made. The procedure does not rely on a poorly-tested, general hypothesis of urban growth; yet it is producing the kind of material that is needed in large quantity to develop and test a general theory. In other words, continuing land-use inventories and accompanying cumulative time-series maps would serve both practical and theoretical purposes.

On the practical side, the studies described have three immediate uses. (1) They aid in planning land acquisition for highways; for they help to foresee where it is most important to buy right-of-way in anticipation of rising land costs and future traffic. (2) They are of value in highway programming; for they help to indicate where, when, and how much traffic generation and highway needs will grow in a given metropolitan area. (3) Finally, these studies are of use in comprehensive planning. They encourage the articulation of future plans with existing trends and principles. They increase the likelihood that any plan for the future will be a logical extension of an evolving pattern as well as a desirable theoretical design.

On the theoretical side, a program of continuing land-use inventory and time-series mapping would also make a contribution. It would provide the basic description of the urban land settlement process which is necessary to the development of a viable theory of urban growth.

REFERENCES