marily due to inconsistent modeling of the labor supply-and-demand interactions. The result of the respecification was to produce a less complicated but theoretically more robust model that explicitly recognized the importance of labor-supply adjustments. Yet because certain current and future trends are not adequately reflected in the forecasting process, the forecasts must be interpreted as representing the upper end of possible economic and demographic expectations for KCMR. (Further information concerning the forecasts can be obtained from the Mid-America Regional Council.)

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REFERENCES

1. Regional Employment by Industry, 1940-1970. Bureau of Economic Analysis, U.S. Department of Commerce, 1975.
2. Federal-State Cooperative Program for Population Estimates. Bureau of the Census, U.S. Department of Commerce, Series P-26 for Kansas and Missouri, 1970-1978.
3. Current Population Reports: Population Estimates and Projections. Bureau of the Census, U.S. Department of Commerce, Series P-25, Nos. 721 and 870, 1978 and 1980.
4. IPEF 73: Interactive Population and Employment Forecasting Model Technical Users' Manual. Comprehensive Planning Organization of the San Diego Region, San Diego, CA, 1974.
5. Current Population Reports: Population Estimates and Projections. Bureau of the Census, U.S. Department of Commerce, Series P-25, Nos. 601 and 704, 1975 and 1977.
6. Employment and Earnings (United States and states and areas). Bureau of Labor Statistics, U.S. Department of Labor, 1962-1977.
7. County Business Patterns. Bureau of the Census, U.S. Department of Commerce, Vols. CB18-CBB27, 1959-1977.
8. Current Population Reports: Population Characteristics. Bureau of the Census, U.S. Department of Commerce, Series P-20, No. 305, 1977.

Evaluation of Two Residential Models for Land Use Allocation

C. J. KHISTY

The current thrust in transportation planning is to make greater use of manual and partly computerized techniques for providing quick-response travel estimation. In this context, land use models, which fuel the typical transportation models, are needed for small and medium-sized cities that operate on a small budget. The results of the evaluation of two operational residential land-use-allocation techniques most suitable for use in small and medium-sized cities are recorded. In an ex post facto test, both techniques were applied in a common setting and the U-statistic was used as a measure of performance. The results were excellent.

The transportation-planning process formalized in the early 1960s became increasingly diversified in the 1970s. This change also affected models for land use allocation, which fuel the typical four-step sequential transportation models. Recently, special attention has been focused on the planning processes for small and medium-sized communities. This paper records the results of an evaluation of two operational techniques for forecasting residential land use most suitable for use in small and medium-sized cities. The first technique tested is the Chicago Area Transportation Study (CATS) method or the Density-Saturation Gradient (DSG) method, which is a simplification of the CATS method (1). The second technique tested is a method of land use forecasting in which the concepts of holding capacity, logistic curves, rates of land consumption, and residential development factors are used. This model will be referred to as the HCLC method in this paper. The method has recently been documented (2).

The testing and evaluation of these two models were performed by applying them in a common setting. The research was not prompted by the desire to proclaim a winner from among the models tested. These two operational residential-forecasting methods were applied to the city of Toledo, Ohio, which was chosen primarily because it was felt that Toledo's size (1974 population, 332 240) was representative of the city for which forecasting techniques of this kind would be most appropriate. Toledo was also chosen because of my knowledge of the city and its environs. This acquaintance with the area is almost a prerequisite for applying the manual techniques of land use forecasting described. Another reason for choosing Toledo was that a rather extensive information file on a small-area basis is available for two time periods--1965 and 1974. Thus, the two techniques were used to forecast land use for 1974 given the 1965 base.

METHODOLOGICAL PROBLEMS

The two traditional manual-forecasting techniques described here are theoretically simple and operationally straightforward. At the same time, it must be said that, although the allocation process in such models is based on acceptable planning standards, it is also dependent on professional judgment, which can at times be subjective, even though such judgments are buttressed by principles and techniques of planning.

DATA SOURCES

The data for testing these two techniques of land use forecasting came from several sources, chiefly the Bureau of the Census, publications of the Toledo Regional Area Plan for Action (TRAPA), and the city of Toledo. It is important to state that, since these tests were conducted ex post facto, no information beyond 1965 was used. Indeed, great care was taken to completely eliminate all information and data available after 1965, except the total 1974 population, derived exogenously.

MODEL PERFORMANCE AND U-TEST

The U-test, a standardized statistical test, was used to establish the reliability of model forecasts. The U-statistic is a measure of the statistical correlation between two sets of data, whereas the U-test is a statistical-distribution test that measures the agreement between the forecast item and the observed item frequency. The accuracy of the forecast is judged by the magnitude of the U-value. The U-statistic is calculated as follows:

$$U = \{[(1/N)\,\Sigma(S_i - C_i)^2]^{1/2}\}/\{[(1/N)\Sigma(S_i)^2]^{1/2} + [(1/N)\Sigma(C_i)^2]^{1/2}\} \qquad (1)$$

where

S_i = projected value of zone i,
C_i = actual value of zone i, and
N = number of intervals in the distribution.

In general, a value of U less than 0.1 is considered good; a value between 0.1 and 0.3, average; and a value more than 0.3, poor (3).

DSG METHOD

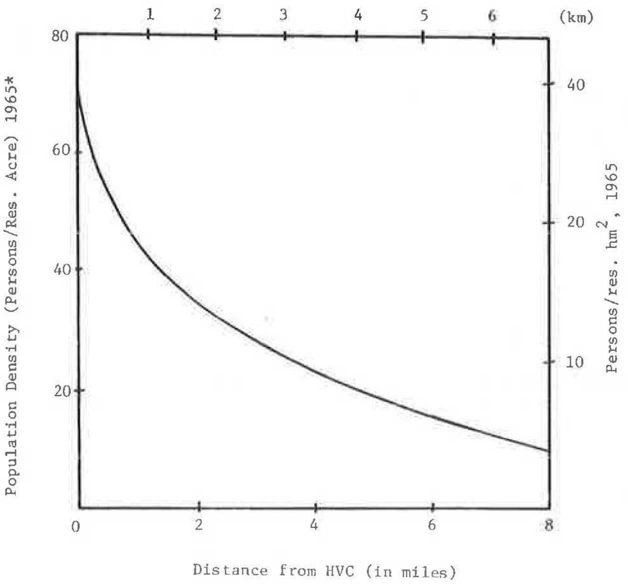
The density-saturation gradient is, as the name suggests, a plot of the residential saturation as a function of distance or travel time from some convenient reference origin--usually the city center. It is a function that can be determined experimentally for any city, although practical difficulties are encountered because of topographical and zoning peculiarities. It is sometimes necessary to define the function separately for a number of sectors of the surrounding metropolis. The only known previous application of this approach has been for the Chicago area. Swerdloff and Stowers (4) later applied it in a test situation to Greensboro, North Carolina, and the procedures detailed in their paper are used here.

The DSG method was applied to the city of Toledo by using airline distance from the high-value corner (HVC) as the key spatial variable. HVC is a point representative of the hypothetical activity center of the central business district (CBD). Figure 1 shows the relationship between 1965 residential density and airline distance from HVC. Each point on this plot represents the residential density for a ring around HVC. The decline in density results from the operation of the competitive land market.

Each ring is defined by the boundaries of all census tracts the centroids of which fall within ±0.5 mile of the distance of the ring from HVC, with the exception of the first, or CBD, ring. The plot indicates a regular decline in residential densities with distance from HVC. The next step is to compute the holding capacity. Mathematically, the holding capacity of an area is defined as the existing population plus the product of vacant, available, and suitable land and the expected residential density. Theoretically, this density is the anticipated average density at which all future residential development will occur.

These values can be developed from an intensive analysis of trends in residential density patterns and zoning policies. For purposes of this investigation, future densities for each census tract are assumed to be those given by the smooth, hand-fitted curve of Figure 1.

Figure 1. Population density by distance bands, 1965.



Vacant, suitable land for residential development was estimated from figures available from data for planning areas. Also, from zoning ordinances and zoning plans, it was possible to estimate land available or earmarked for residential use. Once future residential densities and vacant, available land for residential use had been determined, it was possible to compute residential-holding capacities and residential saturations (1965 population versus residential-holding capacity) for each census tract. The latter values were then used to construct the percentage saturation gradient for 1965 (curve a, Figure 2). No particular judgment decisions were needed or used up to this point in the forecasting procedure.

The plot of the 1965 population versus residential-holding capacity conforms very well with the expected plot for an urban area, as shown in Figure 2. The next step was the 1974 projection of the percentage saturation curve, also shown in Figure 2. This is the most critical and subjective step in the forecasting process, since the only restraint on the projected curve is that the area under the new curve account for the existing plus the projected regional growth. The population in the study area grew from a 1964 total of 324 385 to 332 240 in 1974, or a growth of 2.42 percent. From trends of population movement it was generally known that the center city was rapidly losing population and that areas outside the study area were gaining population.

One can proceed in an almost infinite number of ways in establishing an acceptable projection of the percentage saturation gradient for 1974 population. However, it was found useful first to develop a feel for the overall scale of the problem. The following procedural steps were considered in order to determine the 1974 saturation gradient:

1. By using the 1950 and 1960 census figures for population, saturation gradients for 1950 and 1960 were constructed similar to curve a in Figure 2. From these curves it was observed that the population at the city center was declining and the slope of the saturation gradient was becoming flatter.

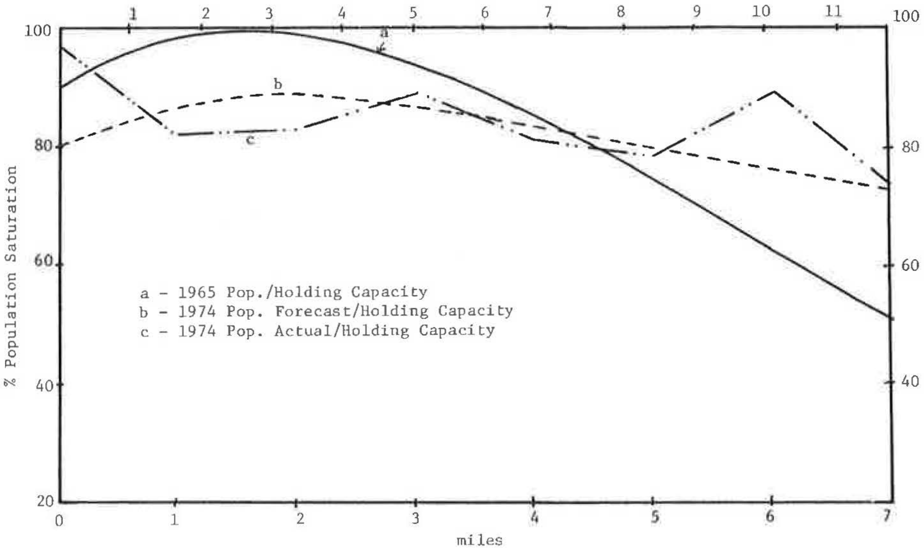


Figure 2. Percentage saturation gradients for 1965, 1974 forecast, and 1974 actual population by distance bands.

Thus, the pattern of densities prevailing in 1965 represented a kind of equilibrium between the cost of land, building costs, locational requirements, and transportation costs. Indeed, as shown in Figure 3, the 1950, 1960, and 1965 saturation gradients provided a rough estimate of the proportional changes one could expect for a 1974 saturation gradient.

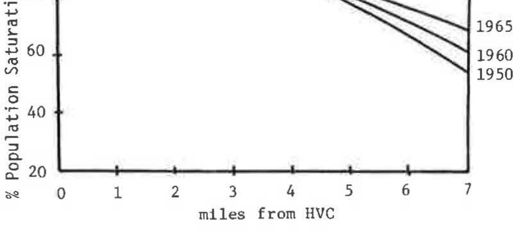
2. Building permits obtained from the city of Toledo for the period 1959-1964 were grouped by census tracts and rings. The increments in housing and thus population were aggregated and used as trends for the 1965-1974 period.

3. The zoning ordinances of the city of Toledo were examined, and census tracts that fell into various categories were aggregated by ring. This helped to set saturation-gradient figures at the ring level.

Based on the results from step 1, a rough 1974 saturation gradient was drawn. This was adjusted to reflect the trend and location of growth obtained from steps 2 and 3. The final adjustment was made to assure that the area under the 1974 curve was commensurate with the 1974 total population.

Several attempts were necessary before a solution that reflected the total 1974 population was obtained. A smooth, hand-fitted curve was then drawn to represent the 1974 saturation gradient (curve b, Figure 2). Multiplying the appropriate ordinate value from this forecast percentage saturation gradient for 1974 by the ring saturation quantities established the forecast population totals by analysis ring.

Figure 3. Percentage saturation gradients for population density for 1950, 1960, and 1965.



The question now remained of distributing these ring totals to individual census tracts. This distribution is dependent on several factors, such as accessibility and water and sewer facilities. In order to measure the strength of the residential-development potential, an activity-allocation process was formulated. Several metropolitan-area transportation studies have used residential-development factors in the past in their activity-allocation process. The specific values assigned to these factors were selected to reflect the comparative impacts that sewer service, water service, accessibility, etc., have on residential growth. Based on these studies, a similar rating procedure was developed for this research that took into account a systematic linear weighting of the following factors: community facilities (sewer, water, school); accessibility (CBD, shopping centers, employment centers, highway and transit systems); and activity patterns (existing land use, recreation).

After the initial distribution from ring totals to census tracts had been performed, two further checks were made: first, to make sure that a particular census tract had not been allotted a population in excess of its residential-holding capacity; and, second, to determine whether a given census tract was in conformity with the applicable zoning ordinance.

HCLC METHOD

The HCLC method combines the concepts of holding capacity, the use of logistic curves, and land-consumption rates in the distribution of an areawide forecast of population to small areas. The HCLC method was applied to the city of Toledo west of the Maumee River to an area identical to that used in the DSG method previously described. The small-area unit used is the census tract. Census tracts that have similar characteristics were grouped into planning areas. Twelve such planning areas were identified.

Table 1 is an inventory of the total acreage, 1965 residential acreage, additional land for residential use, and maximum land available for residential use. The number of dwelling units (DUs) in 1965 (the base year) and the maximum number of DUs

Table 1. Capacity projections of land use by planning area.

	Land Use (hm^2)				DUs		
Planning Area	Total	1965 Residential	Additional Residential	Maximum Residential	1965	Capacity	1965 Percentage of Capacity
Old Orchard	8 838	2531	171	2702	11 531	11 531	100
West Toledo (A)	4 732	2141	30	2171	9 096	9 349	100
West Toledo (B)	4 999	2409	172	2581	7 452	7 452	100
Mayfair	6 457	1428	675	4684	5 127	7 665	66.9
Trilby	8 941	3289	2218	5507	6 212	10 476	59.3
Talmadge	4 162	1671	420	2091	3 150	3 979	79.2
Heatherdowns	12 892	3681	1363	5044	8 183	11 962	68.4
Reynolds Corner	13 041	3351	3186	6537	5 536	11 930	46.4
Airport Highway	6 872	553	1235	1788	797	2 605	30.6
Point Place	5 190	1541	808	2349	4 597	6 116	75.2
Fort Industry	8 810	231	--	231	228	228	100
Inner core					68 785	68 785	100
Lagrange	5 961	1981	75	2056			
Center City	2 090	324	--	324			
Dorr	4 841	2198	--	2198			
North End	4 921	992	--	992			
Old West End	3 355	1731	--	1731			
South Side	7 210	2322	--	2322			

Note: 1 hm^2 = 2.47 acres.

at holding capacity for every planning area are shown.

It was possible to estimate land available or earmarked for residential use from 1965 zoning plans, the land-capability analysis, and 1964 aerial photographs. In the HCLC method, DUs are substituted for population when the holding capacity is calculated. Thus the ratio of DUs in a planning area to the holding capacity determines the stage in the development cycle that the planning area has reached in the base year (1965). It also provides the basis for estimating at which stage the area will be at a future date--in this case, 1974.

The question of establishing the development cycle was taken up next. From previous investigation and analysis, a typical development cycle derived from a logit curve of approximately 50 years was selected (Table 2) and applied to the planning areas to estimate the percentage of growth of DUs in each planning area, depending on the stage of development each area is currently in. This growth is shown in Table 3, which also shows the forecast DUs for 1974. The forecast population for each planning area is shown in Table 4.

The vacancy and occupancy rates adopted in Table 4 were derived by straight-line projections of corresponding 1960 and 1965 figures to 1974. The only information used was the total 1974 population (332 240), derived exogenously. The distribution of the 1974 forecast population by planning areas to census tracts was performed by using the residential-development factors described previously. It may be stated that after the planning-area population had been distributed to census tracts by using the residential-development factors, it was necessary to assure that the zoning ordinances applicable to different areas and census tracts were not violated and also to verify that the residential-holding capacities were not exceeded for any census tract.

Table 2. Development cycle: estimated years required to achieve given stage of development.

Type of Growth	Percentage of Capacity Developed	Annual Growth Rate (%)	Approximate Number of Years in Stage
Very slow	0-10	1	10
Slow	11-20	2	5
Moderate	21-40	3	7
Boom	41-60	4	5
Moderate	61-80	3	7
Leveling off			
Fast	81-90	2	5
Slow	91-100	1	10
Total			49

PERFORMANCE

The U-test was applied to both models and computed at two levels of aggregation, the ring and the planning area. The ring is associated with the DSG method, whereas the HCLC method uses the planning area. U-values are given below for both methods:

	U-Value	
Method	Ring	Planning Area
DSG	0.0383	0.021
HCLC	0.0421	0.034

Since all the values of U are less than 0.1, one could easily acclaim that both methods produced excellent results.

The DSG method is simple, straightforward, and easy to operate even for cities the size of Toledo. The only difficulty was setting up the 1974 density curve. Several trials had to be made before the area under the curve was commensurate with the area population.

The HCLC method was equally simple and straightforward except for the calibration of the logistic curves. It may have been easier to set up these curves and obtain more-accurate growth rates had there been sufficient historical data available.

Overall, the results produced by these two simple models for land use allocation were very promising. Once the data were available, it took roughly 50 person-h to run each model. No attempt was made to keep track of the time required to collect and tabulate the data.

CONCLUSIONS

The two traditional manual methods for forecasting land use described in this paper are sufficiently accurate to be recommended for small and medium-sized cities. Both methods almost force the analyst to become intimately familiar with the study area, its zoning ordinances, its physical characteristics, and its growth trends before attempting to fore-

Table 3. Forecast growth of DUs in planning areas, 1965-1974.

Planning Area	DUs in 1965	Percentage of Growth by Annual Growth Rate[a]							1974 Forecast DUs
		1 Percent	2 Percent	3 Percent	4 Percent	3 Percent	2 Percent	1 Percent	
Old Orchard	11 531	No expansion							11 531
West Toledo (A)	9 096	No expansion							9 096
West Toledo (B)	7 452	No expansion							7 452
Mayfair	5 127					3/4[b]	2/5		6 371
Trilby	6 212				4/1	3/7	2/1		8 104
Talmadge	3 150					3/1	2/5	1/3	3 690
Heatherdowns	8 183					3/4	2/5		10 168
Reynolds Corner	5 536				4/3	3/6			7 436
Airport Highway	797			3/3	4/6				1 102
Point Place	4 597					3/2	2/5	1/2	5 493
Fort Industry	228	No expansion							228
Inner core	68 785		3/9 (decline)						51 589

[a] Percentage of growth per year per number of years. [b] Denotes 3 percent growth per year over a four-year period.

Table 4. Forecast and actual population, 1974.

Planning Area	1974 Forecast DUs	Vacancy Rate (%)	Occupancy Rate (persons/DU)	1974 Forecast Population		Actual 1974 Population	Ratio Forecast/ Actual
				Raw	Final		
Old Orchard	11 531	4.1	2.6	28 751	30 220	27 530	1.10
West Toledo (A)	9 096	3.1	2.7	23 798	25 014	25 111	1.00
West Toledo (B)	7 452	3.4	2.8	20 156	21 186	21 395	0.99
Mayfair	6 371	3.0	3.0	18 540	19 487	18 474	1.05
Trilby	8 104	2.6	3.1	24 471	25 721	29 935	0.86
Talmadge	3 690	2.6	2.8	10 065	10 579	11 314	0.94
Heatherdowns	10 168	3.4	3.0	29 469	30 975	36 574	0.86
Reynolds Corner	7 436	2.7	3.0	21 704	22 813	21 151	1.08
Airport Highway	1 102	3.6	3.0	53 187	3 350	4 387	0.76
Point Place	5 493	2.5	3.1	16 602	17 450	16 652	1.04
Fort Industry	228	2.5	3.3	733	770	514	1.50
Inner core	51 589	4.2	2.4	118 612	124 675	119 203	1.05
				316 088	332 240	332 240	

cast. This is considered a positive feature of the methods. In any case, the methods of analysis described here are useful tools that can stand on their own or even serve as checks on the reasonableness of forecasts produced by the more-sophisticated computer-oriented models.

REFERENCES

1. J.R. Hamburg and R.H. Sharkey. Land-Use Forecast: Chicago Area Transportation Study. CATS, Chicago, IL, 1961.
2. C.J. Khisty. Land-Use-Allocation Model for Small and Medium-Sized Cities. TRB, Transportation Research Record 730, 1979, pp. 34-38.
3. ITE Technical Committee 6F6. Land Use and Demography: Growth Versus Forecast. Transportation Engineering, Vol. 47, No. 3, March 1977, pp. 42-44.
4. C.N. Swerdloff and J.R. Stowers. Test of Some First-Generation Residential Land-Use Models. HRB, Highway Research Record 126, 1966, pp. 38-59.