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We, the authors, accept sole responsibility for the contents of this paper.

REFERENCES

1. K. E. Heanue. Changing Emphasis in Urban Transportation Planning. Presented at the 56th Annual Meeting, TRB, 1977.
2. H. S. Levinson. Characteristics of Urban Transportation Demand: A New Data Bank. TRB, Transportation Research Record 673, 1978, pp. 53-59.
3. A. B. Sosslau, A. B. Hassam, and M. M. Carter. Manual Techniques and Transferable Parameters for Urban Transportation Planning. TRB, Transportation Research Record 673, 1978, pp. 32-40.
4. Transportation Planning in Small Urban Areas: The Appropriate Level of Effort. Federal Highway Administration, U.S. Department of Transportation, 1977.
5. S. Kristoffersen and E. M. Wilson. Trip-Generation Synthesis for Small and Medium-Sized Cities. TRB, Transportation Research Record 638, 1977, pp. 18-21.
6. I. W. Burr. Applied Statistical Methods. Academic Press, New York, 1974, p. 419.
7. Traffic Simulation Model Procedures Report for Columbus: Bartholomew County Transportation Study. Vogt, Sage, and Pflum Consultants, Indianapolis, June 1976.
8. Y. Chan. Review and Compilation of Demand Forecasting Experiences: An Aggregation of Estimation Procedures. Pennsylvania Transportation Institute, Pennsylvania State Univ., University Park, June 1977.
9. J. Bates. Development and Testing of Synthetic Generation and Distribution Models for Urban Transportation Studies. State Highway Department of Georgia, Atlanta, 1971.
10. W. L. Grecco and others. Transportation Planning for Small Urban Areas. NCHRP, Rept. 167, 1976.
11. H. Kassoff and H. D. Deutschman. Trip Generation: A Critical Appraisal. HRB, Highway Research Record 297, 1969, pp. 15-30.
12. R. Dobson and W. E. McGarvey. An Empirical Comparison of Disaggregate Category and Regression Trip Generation Analysis Techniques. Transportation, Vol. 6, 1977, pp. 287-307.
13. Trip Generation Analysis. Federal Highway Administration, U.S. Department of Transportation, Aug. 1975.
14. A. Chatterjee, D. R. Martinson, and K. C. Sinha: Trip Generation Analysis for Regional Studies. Transportation Engineering Journal, ASCE, Vol. 103, Nov. 1977.
15. E. J. Kannel and K. W. Heathington. Temporal Stability of Trip Generation Relations. HRB, Highway Research Record 472, 1973, pp. 17-27.
16. H. F. Wooton and G. W. Pick. A Model for Trips Generated by Households. Journal of Transport Economics and Policy, Vol. 1, May 1967, pp. 137-153.
17. W. Y. Oi and P. W. Shuldiner. An Analysis of Urban Travel Demands. Northwestern Univ. Press, Evanston, IL, 1962.

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Land-Use-Allocation Model for Small and Medium-Sized Cities

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A residential land-use-allocation model most suitable for use in small and medium-sized cities is described. It can also be used in large metropolitan areas to serve as a check or backup method on the reasonableness of forecasts produced by more sophisticated models. The model makes use of Gompertz curves and the concept of holding capacity to allocate regional totals to planning areas. Residential development factors are then used to further distribute these planning-area totals to small areas such as census tracts or traffic zones. In an ex post facto test of this model in which the U-statistic was used as a measure of performance, the accuracy of the method was found to be excellent in comparison with that of sophisticated, computer-oriented urban development models. Use of the procedure will save money, time, and personnel, all of which are important considerations for planning organizations that work under a fixed budget.

Land-use-allocation models fuel the typical four-step sequential transportation models. The general land-use model used in this process takes areawide forecasts of several socioeconomic variables as control totals and uses some procedure to allocate them to small areas, usually traffic analysis zones. The allocation procedures currently used by transportation planning agencies range from traditional "manual" techniques to sophisticated urban development models such as the Projective Land-Use Model (PLUM). Many small and medium-sized cities do not have the expertise, time, or money to run these large-scale models but prefer to rely on simple, less expensive, and more transparent models. Such methods, however, have not been generally developed and validated.

This paper describes a simple method of land-use allocation for small areas, in which the concepts of holding capacity, Gompertz curves, rates of land consumption, and residential development factors are used.

Although many transportation study areas (1-3) have in the past used some of the concepts mentioned above in distributing areawide totals of population and other socioeconomic variables to small areas (such as planning areas, census tracts, and traffic analysis zones), these concepts have not been collectively used and tested in any one study.

CURRENT PRACTICES AND PROBLEMS

Land-use models are concerned with providing small-area forecasts of population and employment in a suitable form for input to a trip-generation analysis. Beginning in the 1950s with metropolitan transportation studies, numerous attempts have been made to forecast these phenomena by using varying degrees of complexity and with widely varying degrees of success. By the mid-1960s, a number of rather large efforts to forecast metropolitan dynamics by the use of computer simulation had been undertaken.

One general approach to land-use forecasting might be called the "planned requirement approach." A traditional method, it derives from a precomputer technology. The most complete and widely used formulation of this approach is that of Chapin (4). The main analytic components of this procedure are, for each land-use category, a set of location requirements and a set of space requirements. Specific rules for the resolution of conflicts among land uses competing for a site are not defined in this approach. These judgments must be made by the analyst, based on given principles and standards, special knowledge of local conditions, and what is considered to be in the best interest of the public.

The other and more sophisticated approach to land-use forecasting is the "market simulation approach". The archetype of this system of models was developed in the early 1960s by Lowry of the Rand Corporation (5). The general structure of the Lowry model, which has since been imitated, altered, and expanded, has been used in large metropolitan studies in recent years. Partly because of the overoptimistic outlook of their creators and partly because of the unrealistic expectations of their potential users, many of these efforts have been partial failures (6).

Most important, such models make heavy demands on the expertise and time of a metropolitan-area study staff and on the study budget. Most metropolitan-area studies would, for these reasons, like to rely on simple, less expensive, and far more transparent urban models. The model described here is one that meets this description.

METHODOLOGY

In this procedure, a thorough knowledge of the local area is assumed as a prerequisite for analysis and planning. It is assumed that the planner will use prescriptive planning dictated by the goals and objectives of the region—tempered, if necessary, by trend analysis—as opposed to purely predictive planning. The sequence of operations is as follows.

Surveys, Regional Totals, and Patterns of Land Consumption

A traditional survey of all existing land uses in the region is required. Additional studies such as a "land capability study" for the region can be very useful (7). In this study, factors such as soil, slopes, floodplains, woodlots, noise hazards, access, and utilities are incorporated into a rational quantitative and inductive system for determining the "ideal" feasible use of land over the long-term future for currently undeveloped or developing areas.

Inventories and areawide forecasts of economic activity and population are, of course, necessary. The land-use inventories should include historic development trends; topographic and physical constraints on development; square hectometers of land in urban use; square hectometers of vacant land, classified as unusable or usable and as publicly or privately owned; location of major travel generators; identification of neighborhood and community boundaries; and nature of land-use controls (8).

The rate at which vacant land is being absorbed into urban use is important in land allocation. This is determined by establishing current rates of land-use consumption. These rates are defined as the amounts of land (measured in square hectometers) brought into urban use by a one-person increase in population or employment.

With the help of regional base-year totals for population and employment, rates of land-use consumption are established for the base year for at least the following categories: residential, commercial, industrial and utility, recreational-institutional, roadways and agricultural, and vacant. Projecting this rate of land-use consumption for a future horizon year depends for the most part on the size, density, and locational preference of the population.

Goals, Objectives, Regional Totals, and Conceptual Land-Use Plans

Through public participation, a survey of community attitudes and preferences is made with regard to housing, shopping, public transportation, neighborhood characteristics, mobility, recreation, regional environment, urban services, and public expenditures. These preferences are reflected in a set of goals, objectives, and policies and also in a set of conceptual land-use plans.

There are several organizational congeries in the land market, and it is best to involve them in the final structuring of the concept plans (9). The first and most important of these congeries is the real estate and building business. The second is made up of larger industries, businesses, and utilities (although they may not consume the greatest quantities of land, they do purchase the largest and most strategic parcels). Individual homeowners and other small consumers of land form the third social constellation. The fourth organizational complex is composed of the many local government agencies that deal with land, such as zoning boards, planning commissions, school boards, traffic commissions, and other agencies. It may be best to meet individually with each of these groups to develop concept plans and then, if necessary, to blend them all together.

Land-Use and Socioeconomic Distribution to Planning Areas

Suitable planning areas, which consist of census tracts that have similar socioeconomic characteristics, are demarcated. The distribution of residential capacity to these planning areas is now undertaken. The concept of full development, or "holding capacity", is used in performing this distribution, for which the maximum amount of developable land in each planning area is established. The holding capacity of an area is the existing population plus the product of vacant, available, suitable land and the expected density. Dwelling units can be substituted for population in calculating holding capacity. Thus, the ratio of dwelling units to holding capacity in a planning area determines what stage in the development cycle the planning area has reached in the base year. It also provides the basis for estimating at which stage the area will be at a future date—say, the horizon year.

The question of establishing the development cycle is taken up next. The time required for each planning area to move from its current state to full development varies by the size of the area, its distance from existing urbanization, and the relative attractiveness of the area for development. This progression of development can be represented by a set of Gompertz curves (also known as logistic curves) to show typical patterns of growth for different planning areas (10). The general form of the Gompertz curve is given by the expression

$$P_t = L/(1 + P_0 e^{-bt}) \quad (1)$$

where

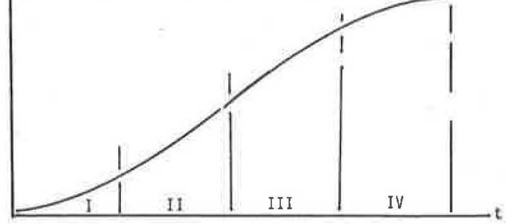
P_t = population at time period t,
L = some estimated maximum population (holding capacity of the area),
P_0 = population at an arbitrary starting point in time,
b = rate at which population increases in time, and
t = time or some index of time.

The setting up of these working curves would need some historical sample data and calibration for establishing the value of parameter b.

Generally, four distinct stages of growth can be identified (see Figure 1). For example, first comes a very slow period of development in which areas move from totally rural to rural plus nonfarm. This stage is followed by a period of slow growth, often without total public utilities. Then comes a rapid-growth, or "boom", period, often heralded by, say, the installation of public sewers. Finally, a slow-growth period sets in as total capacity is reached. These Gompertz curves provide the rates of growth for individual planning areas. Future dwelling units for each planning area are then calculated based on projected average densities for both single- and multiple-family units. Multiplying the projected number of dwelling units by persons per household gives the future population.

The planning-area totals of population are then further distributed to census tracts and traffic zones by making use of residential development factors. These factors are dependent on several criteria, such as accessibility; water and sewer facilities; proximity to schools, employment centers, and shopping centers; and existing land use. Thus, the residential development factor for a given census tract provides a measure of the strength of the development potential and is used to allocate the planning-area total to the various census tracts. This process of activity allocation, like most manual distribution techniques, depends on judgment based on the understanding of the factors that promote growth. A typical set of residential development factors is given in Table 1. Zoning plans, aerial photographs, and the results of a land capability study can also be extremely helpful.

Figure 1. Gompertz (logistic) curve showing typical stages of growth.



ILLUSTRATIVE EXAMPLE

A four-celled region will help to illustrate how the areawide totals of population are allocated to planning areas. Assume that the base year is 1978 and that the 1990 total population has been projected exogenously to be 72 000. Table 2 gives the basic information for each planning area. The additional land for residential use shown in this table can be calculated based on a set of assumptions. A typical set is shown below only for the purpose of this example; more elaborate and extensive assumptions may have to be established in real-world situations:

1. A deduction is made that reflects the fact that only 95 percent of the total land can be developed because of factors such as parcel shape, size, and ownership.
2. Physically constrained land is removed from the potential residential land.
3. Vacant land "committed" to nonresidential uses—such as industry, commerce, or major institutions—is subtracted. The committed uses are determined from

Table 1. Typical residential development factors.

Factor	Points
Community facilities	
Central sewer system service	
Existing (1965)	20
Planned to be in operation by 1980	15
Planned to be in operation by 1990	10
Central water service	
Existing (1965)	20
Planned to be in operation by 1980	15
Planned to be in operation by 1990	10
School, elementary school within 0.8-km radius	5
Accessibility	
Central business district	
0-5 min	5
6-10 min	3
≥11 min	0
Major shopping center	
0-5.5 km	5
5.6-10.8 km	3
≥10.9 km	0
Within census tract	0
Major employment center	
0-5 min	5
6-10 min	3
≥11 min	0
Within census tract	0
Highway system, census tract within 2.4 km of major arterial or freeway interchange	10
Mass transit system, established bus route within 0.4-0.8 km of census tract	5
Activity pattern	
Existing land use	
Industrial park	0
Subdivision	4
Commercial center	0
Population change, 1978-1990	
>25 percent	4
10-25 percent	2
<10 percent	0
Major recreational center	
Park within 3.2 km of census tract	4
Park within 8.0 km of census tract	2
Park available beyond 8.0 km of census tract	0

Note: 1 km = 0.62 mile.

Table 2. Capacity land-use projections by planning areas.

Planning Area	Total Land (hm^2)	1978 Residential Land (hm^2)	Additional Land for Residential Use (hm^2)	Maximum Land for Residential Use (hm^2)	1978 Dwelling Units	Dwelling Units at Capacity	1978 Dwelling Units as Percentage of Capacity
A	1056.1	233.6	110.4	344.0	5127	7 665	66.9
B	1462.4	538.0	362.8	900.7	6212	10 479	59.3
C	2133.0	548.1	521.1	1069.2	5536	11 930	46.4
D	1124.0	90.4	202.0	292.4	797	2 605	30.6

Note: 1 hm^2 = 2.47 acres.

Table 3. Development cycle: estimated years required to achieve given state 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			50

existing zoning plans, local master plans, and announced major developments.

4. In addition to subtracting physically constrained land and land committed to major nonresidential activities, a final reduction may represent, say, a 23 percent roadway component and a 12-17 percent figure for residential services such as schools, parks, and commercial areas.

5. Finally, the net vacant residential land is translated into the number of dwelling units of the housing type and density that can be built for the area.

For planning areas that are almost all developed, the calculations of future growth simply reflect the potential development underzoning on the remaining vacant parcels. The typical development density and not the maximum permitted is used. For areas that are one-third to one-half developed, there is usually enough momentum in development trends to give a good idea of ultimate density. In currently rural areas, however, some judgment has to be used to project the ultimate urbanized density of these areas at some point in the distant future when all land use in the region is urbanized. The density to use is determined subjectively based on current densities, zoning on undeveloped land, and the socioeconomic character of the area.

Once the capacity residential land area is estimated, the next step in projecting future development is to assign total estimated dwelling units to the land. This is termed holding capacity and has already been described.

As mentioned before, development cycles are established for each planning area. Sample neighborhoods in these planning areas can be investigated for estimating the average number of years required to achieve a given stage of development. Table 3 gives a typical development cycle of 50 years. In actual practice, several such development cycles would be needed. It may also be noted that the last column in Table 2 provides the ratio of dwelling units to holding capacity in a planning area. This percentage is crucial because it determines the stage at which the area will be in, say, 1990.

The development cycle is then applied to the planning areas to estimate the percentage growth of dwelling units in each planning area, depending on the current stage of development of each area. This growth is given in Table 4, which also gives the forecast dwelling units for 1990. The forecast population for each planning area is given in Table 5. The vacancy and occupancy rates adopted in Table 5 can be derived by straight-line projections from historic data. The only information available is the total 1990 population of 72 000, obtained exogenously. It will be noticed that, since this total does not quite match the raw forecast total of 71 780, each planning-area total is prorated. The distribution to census tracts of 1990 forecast population by planning areas can then be performed by making use of the residential distribution factor analysis, described previously (Table 1).

After distributing the planning-area population to census tracts, it may be necessary to ensure that zoning ordinances applicable to different areas and census tracts are not violated. In this example, a one-shot estimate and distribution have been demonstrated. In the real-world situation, several trial cycles would have to be performed to match the regional control total of population.

MODEL PERFORMANCE

The reliability of the model was tested by using the U-test (11). In an ex post facto test of this method in which the U-statistic was used as a measure of performance, the accuracy of the method was found to be good (12).

CONCLUSIONS

As a viable alternative to the more costly, data-intensive computer models, the "manual" method described in this paper provides a simple, easy-to-understand, efficient procedure for developing land-

Table 4. Forecast growth of dwelling units in planning areas from 1978 to 1990.

Planning Area	Dwelling Units in 1978	Percentage of Growth by Annual Growth Rate[a] 1 Percent	2 Percent	3 Percent	4 Percent	3 Percent	2 Percent	1 Percent	1990 Forecast Dwelling Units
A	5127					3/4	2/5	1/3	6564
B	6212				4/1	3/7	2/4		8601
C	5536				4/3	3/7	2/2		7968
D	797			3/3	4/5	3/4			1193

[a]Percentage of growth per year/number of years.

Table 5. Forecast and actual population for 1990.

Planning Area	1990 Forecast Dwelling Units	Vacancy Rate (%)	Occupancy (persons per dwelling unit)	1990 Forecast Population Raw	1990 Forecast Population Final
A	6564	3.0	3.0	19 101	19 160
B	8601	2.6	3.1	25 970	26 050
C	7968	2.7	3.0	23 259	23 330
D	1193	3.6	3.0	3 450	3 460
Total				71 780	72 000[a]

[a]Control total derived exogenously.

use plans. The method forces the analyst to become intimately familiar with the study area and its zoning ordinances, physical characteristics, and growth trends before attempting to forecast. This is considered a positive feature of this method. Given a fixed budget of time, money, and personnel, simplification of currently used procedures is a prerequisite to the analysis of more alternatives or the incorporation of more impact analysis. Among the important features of this simplified model is the ability to communicate with those responsible for policy and administration and also with the public, both during and after the analysis.

REFERENCES

1. Land-Use and Development Forecast, 1970-2000: Technical Report. Akron Metropolitan Area Transportation Study, Akron, OH, 1976.
2. Population and Economics Study: Small Units Forecasts. Stark County Area Transportation Study, Canton, OH, 1977.
3. 1965 Regional Land-Use Inventory-Analysis and 1985 Forecasts. Toledo Regional Area Plan for Action, Toledo, OH, 1973.
4. S. F. Chapin. Urban Land-Use Planning. Univ. of Illinois Press, Urbana, 1965.
5. I. S. Lowry. A Model of Metropolis. Rand Corp., Santa Monica, CA, 1964.
6. D. B. Lee. Requiem for Large-Scale Models. Journal of American Institute of Planners, May 1973, pp. 163-178.
7. A Manual Land Capability Evaluation and Scoring System for Five Development-Related Uses. Ohio Department of Natural Resources, Columbus, Tech. Rept. 6, 1975.
8. D. K. Witheford. Urban Transportation Planning. In Transportation and Traffic Engineering Handbook, Prentice-Hall, Englewood Cliffs, NJ, 1976.
9. W. H. Form. The Place of Social Structure in the Determination of Land-Use: Some Implications for a Theory of Urban Ecology. Social Forces, Vol. 32, No. 4, May 1954.
10. M. Yeates. An Introduction to Quantitative Analysis in Human Geography. McGraw-Hill, New York, 1974.
11. Institute of Transportation Engineers. Informational Report: Land-Use and Demography—Growth Versus Forecast. Traffic Engineering, March 1977.
12. C. J. Khisty. An Evaluation of Alternative Manual Land-Use Forecasting Methods Used in Transportation Planning. Department of Civil Engineering, Ohio State Univ., Columbus, Ph.D. dissertation, 1977.