Volume Title: Empirical Models of Urban Land Use: Suggestions on Research Objectives and Organization

Volume Author/Editor: H. James Brown, J. Royce Ginn, Franklin J. James, John F. Kain, and Mahlon R. Straszheim

Volume Publisher:

Volume URL: http://www.nber.org/books/brow72-1

Publication Date: 1972

Chapter Title: Bay Area Transportation Study

Chapter Author: H. James Brown, J. Royce Ginn, Franklin J. James

Chapter URL: http://www.nber.org/chapters/c3982

Chapter pages in book: (p. 68 - 77)

8

Bay Area Transportation Study

INTRODUCTION

THE BAY AREA Transportation Study Commission has undertaken a three-part study of alternative land-use–transportation plans for the Bay Area. The first phase is an extensive inventory of employment, population, land use, and traffic patterns. The second stage involves model development for the evaluation of a wide range of alternative land uses and transportation networks. The objective of the second stage is to limit the choices to a small number of feasible alternatives. In a final or third stage these alternatives will be evaluated in much greater detail. The final stage allocation models will generate a more complex set of outputs, which will permit a more detailed and disaggregated transportation network evaluation.

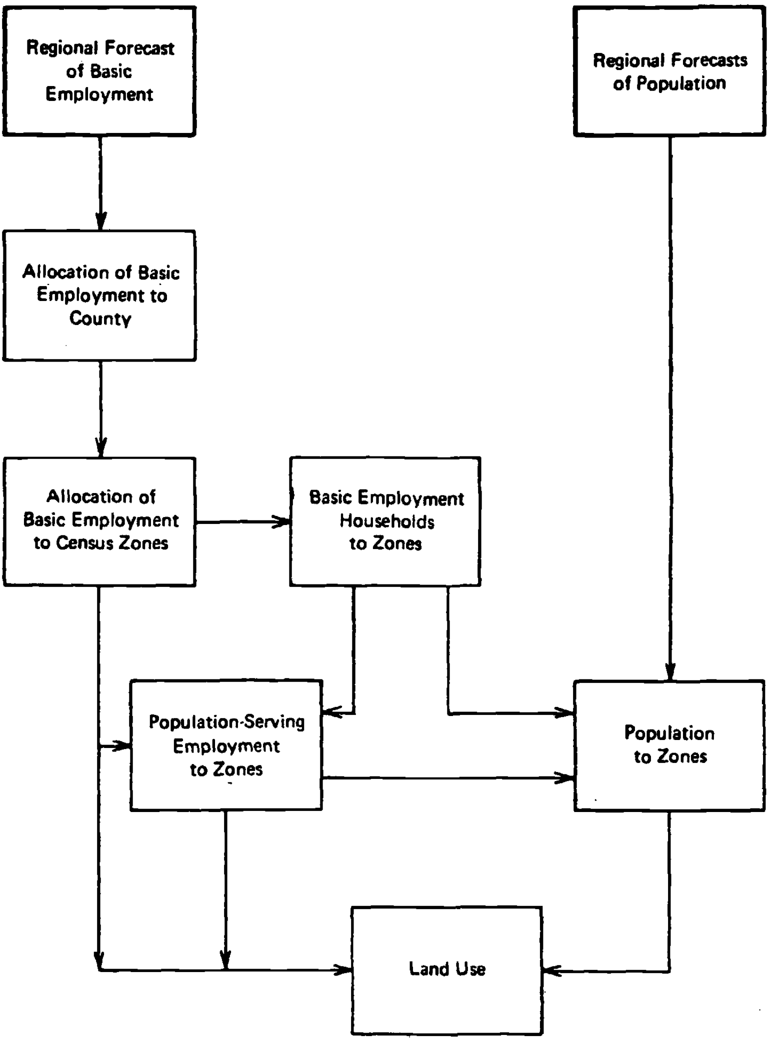
BATS recognizes three allocation problems: location of basic employment, location of population-serving employment, and location of households. The first allocation is handled by a Base Employment Allocation Model (BEMOD). The second and third problems are handled in a Projective Land-Use Model (PLUM). PLUM requires the output of BEMOD (i.e., the location of all base employment) to locate population-serving employment and households. The general structure of the model is shown in Figure 8. At this time, neither BEMOD nor PLUM has been completed, but enough privileged material has been received from William Goldner, Research Director of BATSC, to describe its present structure in substantial detail.

METHODOLOGY

Industry Location

Employment is considered population-serving if its spatial location is determined by the spatial location of households, purchasing power,

Figure 8
Synthesized Flow Diagram for the Bay Area Transportation Land-Use Model



and daytime population concentrations. By contrast, employment is basic if its spatial location is determined by interregional transportation routes, resources and unique features, interindustry linkages, and agglomeration economies. While this distinction is not without difficulties, BATSC feels it is a useful dichotomy for modeling spatial allocation.

In BEMOD, basic employment is divided among eight industry groups (with manufacturing further divided into five subgroups): (1) manufacturing (new technology industries, central office, intermediate, fabricated metals, etc., petro-chemical); (2) transportation; (3) wholesaling; (4) communication; (5) business services; (6) state and federal government; (7) agriculture; and (8) mining.

The spatial allocation of each of these industry groups involves a two-step process. First, industry employment increments are allocated to counties using a shift and share model. Then, these county increments are distributed among census tracts using regression analysis.

The shift and share model requires projections of the employment growth of each of the basic industries for the Bay region. BEMOD uses regression analysis on 1950–65 data to estimate the industries' growth deviations in the county from areawide growth. The independent variables in this analysis are density, a lagged rate of growth, intraregional access, and, in some industry groups, lagged employment. In addition, a special judgmental routine is used to allocate unique location employment. Examples of these unique locators are colleges and universities and air fields. The output of this stage is employment totals for each of the twelve basic industry groups in each of the Bay Area's nine counties.

The second stage of BEMOD allocates these county totals to each of the 742 census tracts of the nine-county area. The routine relies on cross-section regression analysis, using 1964 data. Each of the basic employment groups uses as independent variables some subset of the following eight variables: (1) slope, proportion of tract land area, 0–5 per cent slope; (2) mean elevation of tract; (3) presence of water frontage; (4) presence of rail line; (5) accessibility to population, 1965; (6) employment density; (7) tract land use; and (8) tract share of county employment. The β weights yielded by the regression are held constant throughout the 1968–90 projection period.

The dependent variable in this regression is

$$Z_{ij} = (E_{ij}/L_j)/(E_{ik}/L_k)$$

where i is basic industry class, j is census tract, k is county, E is employment, and L is total land occupied by basic industry. The projected value of Z is then substituted into the following equation:

$$\Delta E_{ij}^{t+1} = Z^*_{ij}\,\Delta E_{ik}^{t+1}\,(L_j^t/L_k^t)$$

where Z^*_{ij} is the estimated value. Tract employment is given by

$$E_{ij}^{t+1} = E_{ij}^t + \Delta E_{ij}^{t+1}$$

where the superscript, t, indicates a time period.

The land absorption coefficients used to convert incremental employment to incremental land requirements are tract specific. If incremental land demanded is less than the land available in a tract, BEMOD simply updates the employment land use and proceeds. If the increment is greater, the employment change of the industry with the lowest Z_{ij} is removed from the tract and is allocated to other tracts where land is available.

Population-serving Employment and Households (PLUM)

Both population-serving employment and household locations are determined by PLUM, which uses both the employment projections and the base employment locations. Further, PLUM makes use of exogenous information from local planning agencies—for example, information on preemption of land by government agencies, important for determining the upper limit on the quantity of land available.

The basic idea behind all of PLUM's allocations is that there is some function which gives the probability that an individual working in i will live t minutes from i or will shop in a store t minutes from i. The distribution function decided upon in all cases is of the following form:

$$P_t = e^{\alpha - \beta / t}$$

where P_t is the probability of an individual living less than t from his place of employment. In order to determine the probability for some interval t to $(t + k)$, it is necessary to evaluate the difference between the cumulative probability at $(t + k)$ and t. Formally, this is

$$P_{(t,\, t+k)} = P_{t+k} - P_t = e^{\alpha - \beta/(t+k)} - e^{\alpha - \beta/t}$$

where $P_{(t,\, t\, +\, k)}$ is the probability of an individual living in the interval t to $(t + k)$.

These functions are fitted separately for each of the nine counties with data from home interviews. The functions were estimated separately for home to work, home to shop, and work to shop. The estimated functions for counties are then applied to the county's zones to derive three matrices of probabilities for each of the trips to every zone.

In order to locate population-serving employment, PLUM makes use of a variant on the base multiplier technique. Instead of relating population-serving employment to base employment, PLUM relates it to base population, that is, base employment plus families of base employees. PLUM gets the latter by distributing base employees to residential zones by means of the home-to-work probability distribution matrix, P_5, and then applying the historical ratio of the nonworking population of each of the zones.

Formally, these two steps are

$$r_1 = P_5 e_1$$

where r_1 is the vector of residences of base employees by zone, P_5 is the matrix of work-to-home probabilities by zones, and e_1 is the vector of base employees by zone; and

$$q_1 = (L - I) r_1$$

where q_1 is nonworking base employment population, L is the diagonal matrix of population per employee by zone, and I is the unit diagonal matrix. The multiplier is then determined as:

$$K = E_3/(1e_1 + 1q_1)$$

where K is base multiplier, E_3 is total nonbase employment in area (exogenously supplied), $1e_1$ is total base employment, $1q_1$ is total nonworking base-related population, and 1 is the unit vector.

Applying the base multiplier to nonworking base-related population at zone of residence and base employment at zone of employment generates demand for population-serving employment by zones:

$$d_{4.1} = Kq_1$$

$$d_{2.1} = Ke_1$$

where $d_{4.1}$ denotes the vector of demand by zones for population-serving nonworking base-related population, and $d_{2.1}$ is the vector of demand by zones for population-serving employment-serving base employment at place of work. It is assumed that the same multiplier generates both home-based and work-based demand.

The next step is to locate population-serving employment by zones. This is done by multiplying the two vectors of demand for population-serving employment by the zonal probability matrix for home to shop and work to shop. As described above, each of these probability matrices is derived from separate allocation functions. The calculations are shown as follows:

$$e_{4.1} = P_4 d_{4.1}$$
$$e_{2.1} = P_2 d_{2.1}$$

where $e_{4.1}$ is the vector of population-serving employment serving nonworking base-related population, $e_{2.1}$ denotes vector of population-serving employment serving base employment, P_4 is the matrix of home-to-shop probabilities, and P_2 is the matrix of work-to-shop probabilities.

Finally, total population-serving employment by zones is obtained by summing work-based and home-based employment

$$e_3 = e_{4.1} + e_{2.1}$$

where e_3 is total population-serving employment. These values are reconciled, zone by zone, to the areawide projection supplied exogenously to PLUM:

$$C(1) = E_3/1e_3$$
$$e_3' = C(1)e_3$$

where $1e_3$ is the sum of the vector of population-serving employment, and e_3' is the adjusted vector of population-serving employment.

The vector of total employment at place of work is obtained by adding the adjusted population-serving employment to the exogenously determined base employment:

$$e_6 = e_1 + e_3'$$

where e_6 is the vector of total employment at place of work.

Given total employment at place of work, it is now possible to reapply the home-to-work probability matrix, P_5, and determine workers by place of residence, r_6. By applying the population-per-worker ratio for each zone, L, it is possible to determine the total nonworking population, q_6, by place of residence. These operations are shown below:

$$r_6 = P_5 e_6$$

$$q_6 = (L - I)r_6.$$

It is then necessary to reconcile this total nonworking population with that given exogenously to the model. The correction factor is applied to each zone's nonworking population, and the adjusted nonworking population is added to workers by place of residence to determine the total population for the zones. These steps are summarized as:

$$C(2) = \frac{Q_6}{1q_6}$$

where Q_6 is exogenously determined total area nonworking population, and $1q_6$ is sum over zones of nonworking population.

$$q_6' = C(2)q_6$$

where q_6' is the adjusted vector of nonworking population.

$$n_6' = r_6 + q_6'$$

where n_6' is the adjusted vector of total population.

A change in the population in each zone with no change in the number of workers suggests a change in the population per worker, L. Further, assuming a constant family size, the above changes would suggest a change in the workers per household, F. It is this latter adjusted value that is used to calculate the number of households in each zone

$$h = Fr_6$$

where h is the vector of households in each zone, r_6 is the vector of base employees by place of residence, and F is the diagonal matrix of households per base employee.

With base employment, population-serving employment, and households located by zone, the next step is to apply land absorption coefficients to each of the activities and to keep an accounting record of land use. Unusable land is first subtracted from the total land supply. It includes naturally unusable land—for example, land that is under water or too steep, and land preempted by public policy. Base-employment land use is supplied to PLUM and accepted without change. Population-serving–employment land use is assumed to preempt residential use. The residual land is available for residential use.

As is apparent from the description of the location of households, land availability is not considered as a constraint. Thus, it is possible that, given the land absorption coefficient for households, more land in any zone may be allocated than is actually available.

PLUM has a routine for reconciling the land allocated to residential use with the land available. First, present capacity in terms of number of households is defined by dividing the present stock of residential and vacant land by the residential land absorption matrix:

$$C^* = A_5^{-1}(a_5^* + a_8^*)$$

where C^* is the vector of residential capacities of zones, a_5^* is the vector of present stock of residential land, a_8^* is the vector of present stock of vacant land, and A_5 is the diagonal matrix of residential land absorption coefficients.

Next, two vectors of capacity utilization are defined. The first measures the initial capacity utilization; the second, the utilization after households have been allocated by PLUM:

$$y_i^* = h_i^*/C_i^*$$

$$x_i = h_i/C_i^*$$

where h_i^* represents initial households in zone i, h_i, the projected households in zone i, y_i^* is present capacity utilization in zone i, and x_i is the projected capacity utilization in zone i. While the elements of the vector y^* must be less than or equal to one, the elements of the vector x can be zero or any positive value. When any element of x is greater than one, more residential land is allocated to that zone than is available.

In order to reconcile the projected spatial distribution of housing units and their associated land requirements with the available supply of land in each zone, PLUM first defines two transformations of the elements of x:

$$y^\circ = 1 - e^{-(e^{x_i}-1)}$$

$$y_i^{\circ\circ} = 1 - e^{-(e^{2x_i}-1)}.$$

Both y_i° and $y_i^{\circ\circ}$ are always greater than or equal to zero, and less than one. Also, except when $x_i = 0$, $y_i^{\circ\circ}$ is greater than y_i°.

Zonal residential densities, and therefore zonal capacities, are adjusted in the model to reflect changes in residential demand. If y_i° is greater than y_i^*, the proportion of capacity initially developed, the zonal residential density is adjusted as follows:

$$G_{i5}' = G_{i5}e^{m(y_i^\circ - y_i^*)}$$

where G_{i5} is original residential density in zone i, m is density transformation coefficient, and G_{i5}' is adjusted residential density in zone i. If y_i° is less than y_i^*, G_{i5} is held constant. The density transformation coefficients are derived for each of the nine counties in the region using cross-section regression analysis.

The vector G_5 is used to define an adjusted zonal capacity, C' is $G_5'\ (a_5^* + a_8^*)$. Using this adjusted capacity and the previously derived constrained measures of the proportion of capacity developed, y° and $y^{\circ\circ}$, two vectors of zonal household allocations are derived: h° equals $y^\circ C^*$ and $h^{\circ\circ}$ equals $y^{\circ\circ} C'$.

The vector $h^{\circ\circ}$ is considered an "upper-limit allocation," and is used in the following definition:

$$W = 1 + \frac{1h - 1h^\circ}{1h^{\circ\circ} - 1h^\circ}.$$

W, a scalar, is used to derive a new vector of zonal development ratios,

$$x' = W\ \frac{h^\circ}{C'}.$$

The elements of this vector are then transformed to derive the final zonal development ratios:

$$y_i' = 1 - e^{-(e^{x'_i} - 1)}.$$

Zonal household allocations are determined by $h'' = y'C'$.

This reallocation routine, of course, changes the spatial configuration of employed residents and nonworking residents. This requires the recalculation and adjustment of these variables to make zonal and areawide totals consistent.

OVERVIEW

Clearly, the BATS models have been designed to accommodate two often conflicting purposes of land-use modeling. First, of course, the models were designed to be an immediately useful planning tool. Second, they have been designed to allow the relatively easy introduction of the results of their continuing program of research on the behavior being modeled.

One area in which research would be of value is in the allocation of population-serving employment. It seems questionable to apply one areawide multiplier to all base employees and all families of base employees. Further, it seems questionable to suggest that the same multiplier will hold for workers at their working places and nonworkers at their residences. This assumption implies that employees do all their spending from their workplaces and that this spending generates the same multiplier as the rest of the family's per capita consumption from the place of residence. It is obvious that the results of future research on disaggregating the multiplier by worker type, working place, family income, family size, and residential location can be easily adapted for input into PLUM.

The model could also easily incorporate the results of research using the same kind of disaggregation for the home-to-work, work-to-shop, and home-to-shop allocation functions.

PLUM introduces changes in residential density with changes in the extent of land development, but no account is taken of changes in employment density. This asymmetry suggests that further extensions in this area might be fruitful.