The Use of Land Development Simulation Models in Transportation Planning

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The Bay Area Simulation Study or BASS Model is a large complex of computer models that has as its goal forecasting future growth within the San Francisco Bay Area. The BASS model is composed of three distinct submodels. The first of these is the employment and population projection submodel that forecasts employment by 21 categories and population totals for the Bay Area over the period from 1970 to the year 2020. The results or the output of this submodel are fed into the two other submodels that allocate projected employment, population, housing, and land development in 777 subareas of the region.

The time required to travel from one place of employment to alternate places of residence is a key determinant of estimated future land use and development in the BASS model. These estimates are made through the use of a time-distance matrix assumedly portraying the time required to travel from the center of any one of the 777 tracts to each of the other tracts in the 13-county Bay Area.

The influence of public policy variables is reflected primarily in the assumptions concerning the usable supply of land and the transportation facilities that will be made available. It has been assumed that current freeway plans approved by the State Division of Highways will be completed on schedule and that the first stage of BART will be completed by 1970 and the second stage by 1980.

•URBAN transportation planning is concerned with one phase of the urban environment, namely the moving of goods and people within and among urban areas. Given the systemic nature of cities, it is impossible to completely divorce the transportation aspects of urban living from the economic, social, and political forces that affect and in turn are affected by the transportation subsystem of the metropolitan region. In their review of the transportation planning process, Memmott, Martin, and Bone make the following observation (1):

> In the planning process, consideration is given to all forms of transportation and to the expected future economic and social development of the area. Because urban transportation studies themselves encompass many varied aspects of the urban environment, they require cooperation, consideration, and support of all organizations and individuals engaged in shaping the future of the urban area. . . .Although many phases of a comprehensive urban transportation study are not the direct responsibility of the transportation planner, still he must be continually aware of the effects his plans will have on other aspects of the urban environment.

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Thus, the goal of transportation planning is much broader than simply planning freeway and/or rapid transit networks. Rather, it is concerned with the greater problem of planning for the general economic and social well-being of the urban area. As such, it constitutes an integral and vital thread in the whole fabric of planning for and within the urban system.

These more inclusive goals of transportation planning have also been stressed by F. Stuart Chapin, Jr., in his Urban Land Use Planning (2). Chapin notes that the land use planning process is not separable from that of transportation planning. "The (transportation) plan which emerges from this process (of integrating land use and transportation planning) represents a choice made from a range of alternatives, each tested for its sufficiency against the goals established at the outset. This plan, together with the land use plan, are the principal components of the general plans" (2, p. 345).

Present techniques of transportation planning consist, in their simplest form, of first analyzing the present transportation system. This is done by such devices as origin-destination studies, measuring traffic flows along major arteries, and measuring passenger volume on transit lines. Next, an estimate of the future growth of the region and its subareas must be derived. Finally, the forecast spatial distribution of economic activity is translated into trips within and among the region and its subareas, disaggregated by mode of travel. This provides a forecast of the demand for different kinds of transportation services. The goal of transportation planning process is to satisfy these demands in a way that is consistent with economic, political, and social plans for the region. The end result of this process is, therefore, a detailed plan of the road and transit systems of the future needed to accommodate projected needs (1).

There were usually one or more weaknesses apparent in previous transportation planning studies. First, many were based on the judgment of local experts who were well versed in the economic, social, and political aspects of the region's past and present. The forecasts deriving from these judgmental studies suffer from a lack of reproducibility by other research teams. Different researchers would probably come up with different conclusions. In any event, judgmental studies are severely handicapped in that they cannot easily take into account the multitude of possible combinations of land use and transportation plans. Thus, each transportation plan must be predicated on a limited number of possible land use plans and behavioral assumptions. In addition, it is extremely difficult in this sort of study to have much feedback between the transportation plan and the land use plan. Judgmental efforts are limited to test a small number of alternatives and are essentially partial equilibrium solutions to the transportation planning problem.

Some of the more recent computerized models (for example, the Bay Area Transportation Study in Berkeley, the Penn-Jersey Transportation Study in Philadelphia, and the Hartford Area Transportation Study in Hartford, Conn.) overcome the lack of reproducibility but are usually deficient in two other ways. First, many of the elaborate computer simulation models of the urban region have not been operational in any meaningful sense (the Penn-Jersey Study for example). In a strict sense these models run on the computer, but the output they produce is often lacking in realism or accuracy. The San Francisco Community Renewal Program (CRP Model) is a good illustration.

Second, those models that have run successfully lack flexibility to test a wide range of alternate assumptions about regional growth in employment and population, about behavioral assumptions such as the actual impediment to interaction posed by time-distance, and about the locational criteria for different types of employment and housing. Finally, the relationship between the transportation system and the economic forecasting model is usually a one-directional relationship. Thus, different transportation plans can be derived from different forecasts of the economic and demographic models, but in general it is more difficult to test the effect of different transportation configurations on the intraregional distribution of employment and population.

The preceding strikes at the need for a more comprehensive transportation planning framework where there is a more explicit interaction between the transportation and land use systems of the region. Support for this statement can be drawn from others who are vastly more experienced in the transportation planning field.

In this vein, Levinson and Wynn remark (3, p. 26),

> The vast impact of transportation facilities on community growth and development requires a total "systems" approach involving all modes of transportation and all interested organizations and governmental agencies. In the past, too many transportation plans, studies, and improvements were developed in relative isolation, concentrating almost entirely on one specific mode, and often overlooking the basic intereffects of "feedback" between transportation and land use.

Similarly, Chinitz observes that "the models are typically designed to forecast the economy and work out the implications for transportation investment, but the reverse relationship in which investments in transportation affect the shape of economic development is not readily taken into account" (4).

Finally, Wilfred Owen draws a similar conclusion and observes that "in a nation that is both motorized and urbanized, there will have to be a closer relation between transportation and urban development. We will have to use transportation resources to achieve better communities and community planning techniques to achieve better transportation. The combination could launch a revolutionary attack on urban congestion that is long overdue" (5).

The need for a more comprehensive approach to transportation problem solving is clear. We present in this paper some background information on a land use forecasting model of the San Francisco Bay Area that meets many of the foregoing criteria. The model called the Bay Area Simulation Study, or BASS (6), is a flexible system comprised of several location and forecasting submodels that yield forecasts for 777 subareas of the San Francisco Bay region disaggregated to 21 industry groups, 6 kinds of housing, and population by 3 income classes. (The 13 counties in the region under consideration are Alameda, Contra Costa, Marin, Napa, Sacramento, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, and Yolo.)

This paper describes the BASS model and its component submodels and emphasizes its flexibility and adaptability to comprehensive transportation planning. Stress is placed on delineating areas, to which the BASS model might be successfully applied, that have heretofore been weak points in the transportation planning process.

THE BASS MODEL

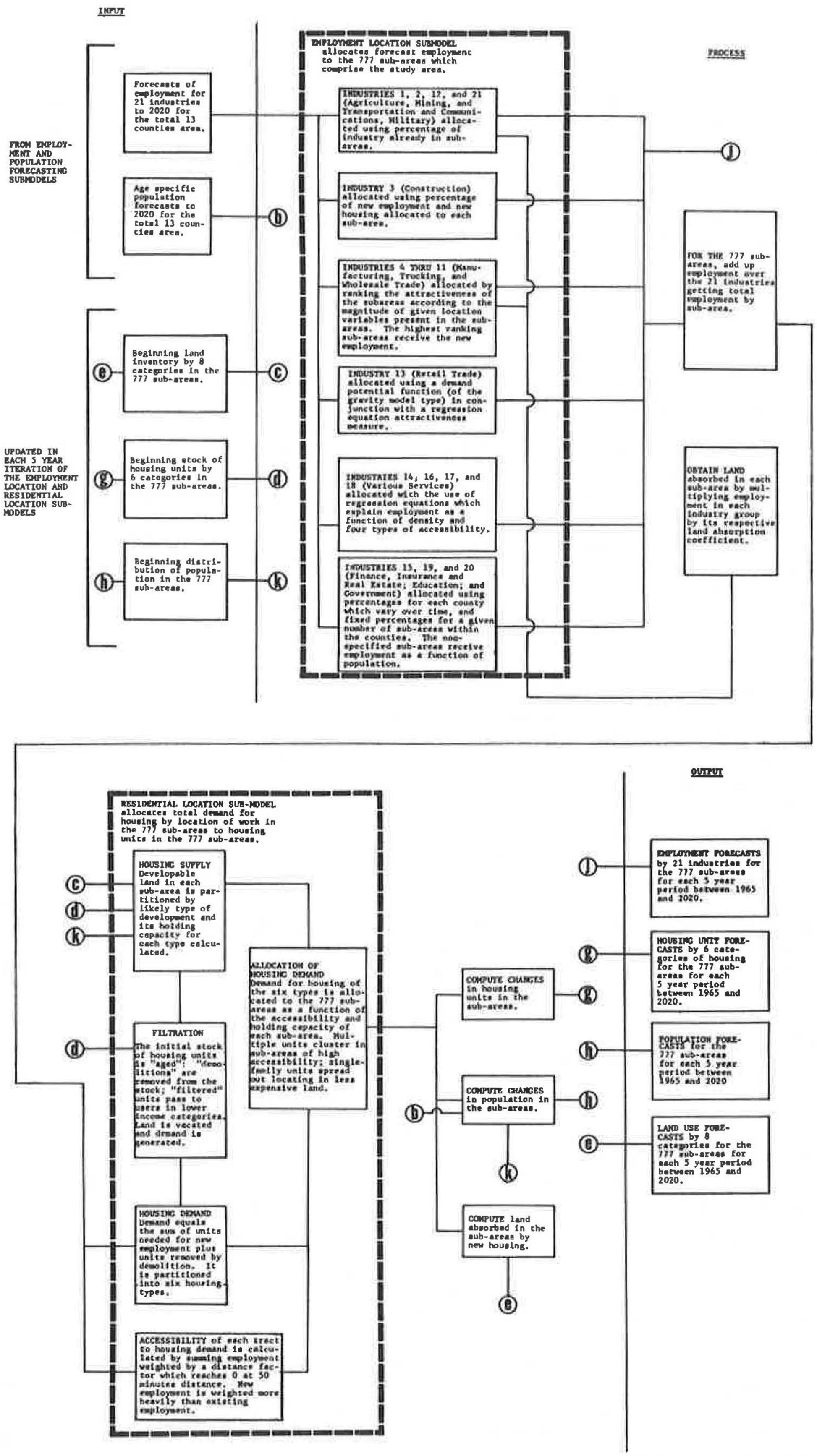
In its simplest terms the BASS model is seen to consist of three distinct submodels:

1. An aggregate forecasting model that projects 21 kinds of employment, and total Bay Area population.
2. A series of employment location submodels that distribute the forecast totals in each of the 21 employment groups to subareas (777 of them) within the Bay Area.
3. A residential location model that distributes population to the subareas. The population is separated according to three income classes, and two structure types for housing (single-family and multiple-family dwellings).

The accompanying two flow charts (Figs. 1 and 2) give a better idea of the flow of information through the model. No attempt is made here to describe the BASS model or its submodels in detail. Rather, a brief overview of each follows so that the general approach can be understood.

The Employment and Population Forecasting Model

Population and employment (by 21 industry types) were forecast using different models that took into account the interaction between migration and employment opportunities. The population model is related to, but strictly separate from, the employment forecasting models. The employment forecast is the result of three employment forecasting frameworks: (a) a structural model based on multiple regression results; (b) a shift model based on differences between national and regional growth rates; and (c) a reconciliation model that combines the structural and shift model forecasts to yield the final employment forecasts.



FROM EMPLOYMENT AND POPULATION FORECASTING SUBMODELS

Forecasts of employment for 21 industries to 2020 for the total 13 counties area.

Age specific population forecasts to 2020 for the total 13 counties area.

UPDATED IN EACH 5 YEAR ITERATION OF THE EMPLOYMENT LOCATION AND RESIDENTIAL LOCATION SUB-MODELS

Beginning land inventory by 8 categories in the 777 sub-areas.

Beginning stock of housing units by 6 categories in the 777 sub-areas.

Beginning distribution of population in the 777 sub-areas.

EMPLOYMENT LOCATION SUBMODEL allocates forecast employment to the 777 sub-areas which comprise the study area.

INDUSTRIES 1, 2, 12, and 21 (Agriculture, Mining, and Transportation and Communications, Military) allocated using percentage of industry already in sub-areas.

INDUSTRY 3 (Construction) allocated using percentage of new employment and new housing allocated to each sub-area.

INDUSTRIES 4 THRU 11 (Manufacturing, Trucking, and Wholesale Trade) allocated by ranking the attractiveness of the subareas according to the magnitude of given location variables present in the sub-areas. The highest ranking sub-areas receive the new employment.

INDUSTRY 13 (Retail Trade) allocated using a demand potential function (of the gravity model type) in conjunction with a regression equation attractiveness measure.

INDUSTRIES 14, 16, 17, and 18 (Various Services) allocated with the use of regression equations which explain employment as a function of density and four types of accessibility.

INDUSTRIES 15, 19, and 20 (Finance, Insurance and Real Estate; Education; and Government) allocated using percentages for each county which vary over time, and fixed percentages for a given number of sub-areas within the counties. The non-specified sub-areas receive employment as a function of population.

FOR THE 777 sub-areas, add up employment over the 21 industries getting total employment by sub-area.

OBTAIN LAND absorbed in each sub-area by multiplying employment in each industry group by its respective land absorption coefficient.

RESIDENTIAL LOCATION SUB-MODEL allocates total demand for housing by location of work in the 777 sub-areas to housing units in the 777 sub-areas.

HOUSING SUPPLY Developable land in each sub-area is partitioned by likely type of development and its holding capacity for each type calculated.

FILTRATION The initial stock of housing units is "aged"; "demolitions" are removed from the stock; "filtered" units pass to users in lower income categories. Land is vacated and demand is generated.

HOUSING DEMAND Demand equals the sum of units needed for new employment plus units removed by demolition. It is partitioned into six housing types.

ACCESSIBILITY of each tract to housing demand is calculated by summing employment weighted by a distance factor which reaches 0 at 50 minutes distance. New employment is weighted more heavily than existing employment.

ALLOCATION OF HOUSING DEMAND Demand for housing of the six types is allocated to the 777 sub-areas as a function of the accessibility and holding capacity of each sub-area. Multiple units cluster in sub-areas of high accessibility; single-family units spread out locating in less expensive land.

COMPUTE CHANGES in housing units in the sub-areas.

COMPUTE CHANGES in population in the sub-areas.

COMPUTE land absorbed in the sub-areas by new housing.

EMPLOYMENT FORECASTS by 21 industries for the 777 sub-areas for each 5 year period between 1965 and 2020.

HOUSING UNIT FORECASTS by 6 categories of housing for the 777 sub-areas for each 5 year period between 1965 and 2020.

POPULATION FORECASTS for the 777 sub-areas for each 5 year period between 1965 and 2020

LAND USE FORECASTS by 8 categories for the 777 sub-areas for each 5 year period between 1965 and 2020.

1. Bay Area Simulation Model (BASS): employment and residential location submodels.

The structural submodel builds on forecasts of 22 state and national economic and financial variables to forecast future employment in each of 21 industries annually for the period 1965 to 2020. The forecasts are for the larger 13-county San Francisco Bay Area, and are aggregated into 5-year periods to coincide with the 5-year iteration cycle of the model. (The iteration period need not be fixed at 5 years. Any suitable length of time is acceptable to the model.)

The shift submodel uses differences between the national and regional growth rates to forecast employment in the same 21 industries. This is a type of trend analysis, and is recommended because of its simplicity.

Finally, the population submodel forecasts future population by applying a range of assumptions concerning birth rates, death rates, and migration to the Bay Area, also on an annual basis. These assumptions appear in the population submodel as parameters, and as better information becomes available, these parameters can be adjusted to reflect these improvements in data.

These three models are all used to obtain the final employment forecast. Future employment, then, is forecast by applying age-specific labor force participation rates to the resulting population estimates. The final output of the employment and population submodels is a judgmental reconciliation of the separate forecasts of the structural, shift, and population submodels. The output of the models provides a medium forecast used as the basic input to the location submodels in Figure 2. Alternatively, an upper and lower range varying by one standard deviation is available for testing the sensitivity of the final output of the location submodels to changes in the long-range employment and population projections.

Employment Location Submodels

The employment location submodels (that appear in the first heavily dotted black box in Fig. 2) employ a variety of different techniques to distribute employment among the 777 subareas of the region. One group of industries, including agriculture, mining, transportation and communications, and military, is allocated in proportion to the magnitudes of existing employment in these groups in each of the subareas. Construction employment is allocated with respect to the amount of new housing and employment in each subarea.

One of the most important employment location submodels is that concerned with the location of manufacturing, trucking and warehousing, and wholesale trade. This can be thought of as the industrial location submodel of BASS. The industrial location submodel deals with eight groups of industries. For each group important locational factors were identified using regression analysis and data gathered from extensive interviews with and a survey of industrial realtors in the San Francisco Bay Area. Having identified these factors, weights were assigned to each factor by industry group. These same factors were then measured for each subarea, and in this way eight attractiveness indices were derived for each subarea (i.e., one index for each industry group). Employment was allocated on the basis of these attractiveness measures.

Retail employment, another important employment group, was allocated using a demand potential function of the gravity model type, suitably modified by the use of a regression equation-derived attractiveness index and by existing retail employment.

Service industries were disaggregated into four large groups. For each group a regression equation was used to explain the location of employment. These equations were adjusted to include existing service employment and new population. Because the regression equation fits were quite high, this procedure has worked quite satisfactorily.

Finally, the forecast employment in finance, insurance, real estate, education, and government is allocated by application of percentages, estimated to change over time, to subareas for each class of employment (for finance, insurance, real estate, and government), and by assuming employment will be a function of population for education.

New employment is allocated for each iterative period among the 777 subareas of the 13 Bay Area counties. These estimates are then converted to estimates of land use by the application of land absorption coefficients, and have been projected to change over time. In the employment location submodels, as in the forecasting models, a wide variety of assumptions has been embodied in the form of parameters with which the mo

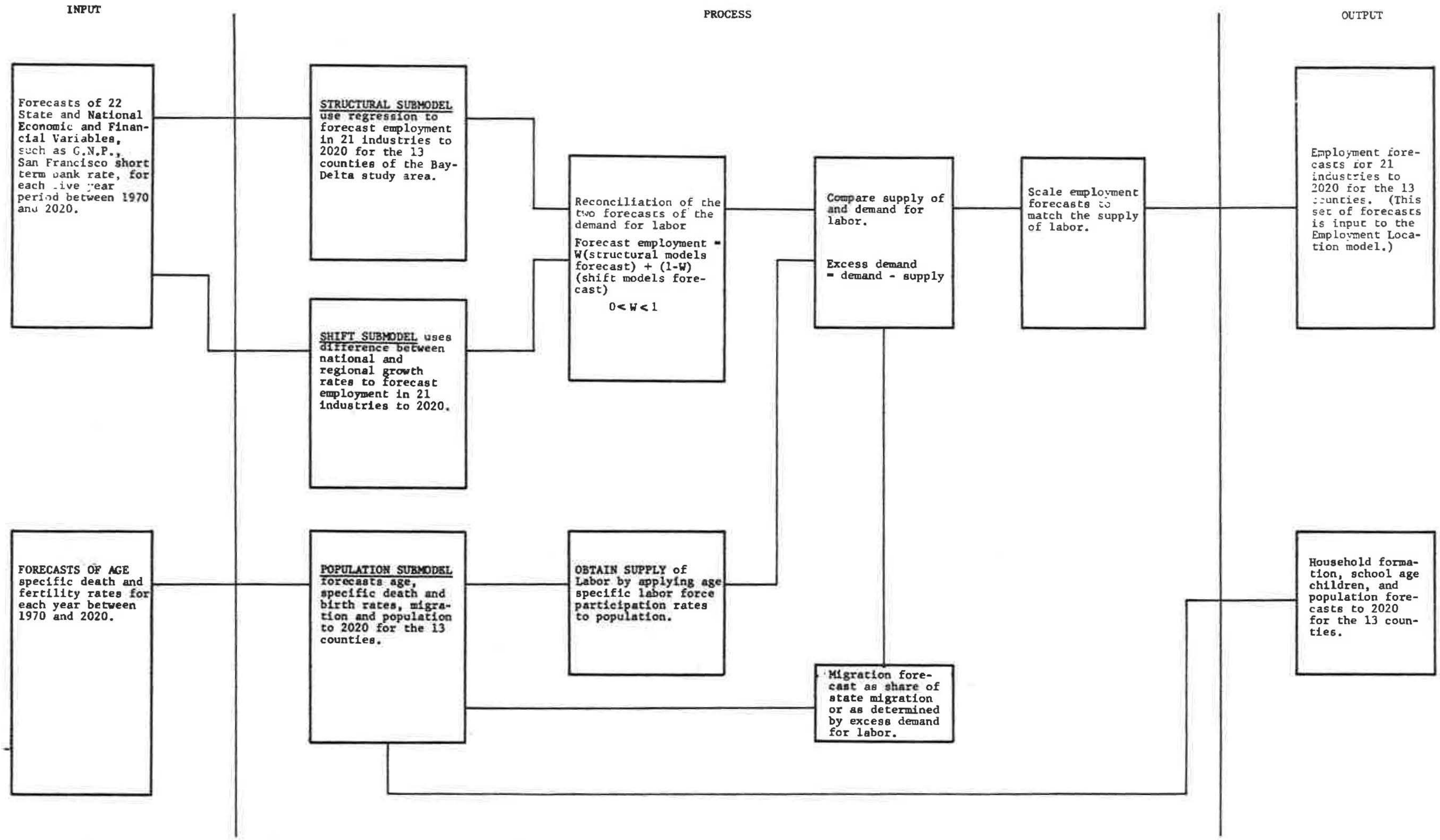


Figure 2. Bay Area Simulation Model (BASS): employment and population submodels.

carries out its calculations. Thus, the weights attached to individual factors in the allocation of manufacturing and service employment are exogenously derived and are supplied parameters that can be varied as better information becomes available. Similarly, the land absorption coefficient can be easily altered with each running of the model. The parameters that can be changed are numerous, and it is sufficient to note here that future findings concerning the location of various kinds of employment can be directly incorporated in the employment location submodels.

The Residential Submodel

The residential location submodel matches the supply of housing and usable land with the estimated housing demand arising from the forecasts of employment and population in the previously described submodels. The inputs to the residential location submodel are identified in Figure 2 by letter designations b, c, d, e, g, h, j, and k, showing the source of each class of input data and the resultant outputs. The model assumes six categories of housing units; i.e., three income classes (high, middle, and low), and two structure types (single-family and multiple-family).

The submodel begins each iteration period with a filtration stage. A set of equations based on the income level of the subarea, the percentage of multiple-family housing units, and the density of development (an analog of density using both employment and population in the numerator) in the area, are used to estimate the shifts in the housing inventory from high to middle income and from middle to low income and from in-stock to out-of-stock.

The supply of usable land for the size categories of housing is then calculated for the 777 subareas. Land available for residential development is considered to include vacant land zoned as residential and agricultural land. The percentage of single-family units to be assigned to a given subarea during an iteration period is determined in the submodel by averaging two ratios. The first ratio is the existing single-family ratio, and the second, weighted twice as heavily as the first, is a function of density of development. The density of development, used as a surrogate for land value, is defined as the sum of population and employment in the subarea, divided by the total usable acres in the subarea.

The total demand for new housing is estimated as the sum of housing removed from the stock by filtration, plus the demand of the new families estimated from the employment and population submodels. This demand is then divided into demand for single-family and for multiple-family units judgmentally with a gradual decrease over time in the percent of single-family.

The partitioning of the forecast housing demand into high-, middle-, and low-income groups for each subarea is made by averaging three estimates using equal weights: the existing division of housing by income classes, an estimate that increases the percentage of high-income housing as a function of density of development, and a third estimate that increases the percentage of high-income housing as the slope of the land increases. The land absorption coefficients used in each subarea are based on the existing density of development.

The allocation of the estimated demand for the size categories of housing to the individual subareas, is made on the basis of the relative accessibility of each area to existing employment, calculated anew for each iterative period. In the 1965 to 1970 iteration, the residential location submodel allocates 30 percent of new housing construction according to accessibility to the location of existing employment to replace stock removed and the remaining 70 percent with regard to its accessibility to new employment. The percentage of the allocation based on accessibility is then increased 3 percent for each 5-year iterative period.

The estimates of population and housing units in the individual subareas are converted into estimates of land use by the use of land absorption coefficients that vary over time with the density of the individual subarea.

Here again note should be made of the flexibility of the residential location submodel. Assumptions regarding the role of accessibility in the location of the six different kinds of housing can be altered in a direct manner. Similarly, the method of partitioning the housing demand into three income classes depends on the relative weights given the three estimates. These weights can also be easily varied. Finally, the split between single- and multiple-family dwelling units can be changed at will as different assumptions seem justified.

THE APPLICABILITY OF BASS TO COMPREHENSIVE TRANSPORTATION PLANNING

The BASS model is immediately applicable to the planning process as it is presently conceived. BASS has been run successfully under a variety of assumptions and the results have been reasonably credible and operationally useful. The model has yielded output that is consistent with the locational trends under way in the Bay Area for the past two decades or more, and the results have been generally similar to county and city projections done by state and local agencies (6, Chap. 6).

The reasonableness of the results is encouraging for those who might desire to use the model for specific applications. The employment and housing forecasts by subarea provide the transportation planner with an alternative basis for generating trips and predicting loadings on the transportation system in the future. This integrated approach to land use and transportation planning fills a long-recognized need.

BASS has additional advantages for the transportation planning process derived from its flexibility. Thus, where traditional transportation studies were concerned with predicting future trip patterns and planning for them, BASS can provide the planner with the ability to test the distribution consequences of a variety of economic forecasts and transportation plans. Such a feedback procedure would certainly go part of the way to eliminating the unidirectional planning process and the criticisms of Chinitz (4), and Memmott, Martin, and Bone (1) noted above. Most important, the cost and time involved in this feedback procedure would be less than that ordinarily expended in the course of the planning process.

The role of the transportation network in the BASS model and its interaction in the forecasts has been ignored so far in this exposition. Transportation plays a key, deterministic role in the model through the matrix of time-distances (6). This matrix (T-D matrix) gives the estimated travel time in minutes at various times among each and every one of the 777 tracts. Thus, there are 777^2 or 603,729 entries (assuming a nonsymmetric pattern of travel times between points). These time distances are the basis for the accessibility calculations used in the employment location and residential submodels for allocating several types of employment (most notably retail trade), population, and housing.

The time-distance matrix can and is modified to reflect the average time-distance between subareas when account is taken of all possible modes. In this way, the entire output from the transportation plan could be used to generate a series of time-distance matrices depending on the relative importance of each mode under each possible plan. The resulting time-distance matrix would embody technological aspects of the plan, such as travel times by each mode, as well as various behavioral assumptions regarding the relative use of each mode.

Thus, the simplest test of the impact of a given transportation plan would be carried out by simply substituting the appropriate time-distance matrix into the model and rerunning it. The cost involved in this kind of change is minimal, and represents a parametric change since the time-distances are really exogenously supplied parameters.

The BASS model has thus been designed to provide the user with the greatest possible flexibility. Some of this flexibility was derived from the parametric nature of the time-distance nature that acted as a focus for all behavioral and technological assumptions about the transportation network (both present and future) and its use. However, as noted previously, there is additional flexibility built into each of the major submodels.

For example, given better estimates of migration, the age distribution of population, labor force participation rates, and so on, new forecasts of employment and population can be generated with virtually no additional effort or cost because provision for employing this information has been built into the employment and population forecasting submodels. In addition, with better information on land absorption coefficients, the industry-specific intrametropolitan location factors, plans for large plants, and the intrametropolitan migration behavior of firms (location forecasts that reflect this information) is obtainable by simply varying about a dozen IBM cards that supply the model with these parameters.

Probably the most important interactions with transportation planning are with the residential location submodel. Here again great flexibility has been provided to reflect changing information on the location of residences. Better behavioral data on the role of accessibility in the demand for different types of housing have direct consequences for the model and can be included simply. Obviously, more accurate time-distance data would improve the accessibility measure and its usefulness in the residential submodel.

Many of the improvements in the BASS model inputs cited above are the outputs of conventional metropolitan transportation studies. Much of this new information can be integrated into the BASS model framework, and technique is not limited to the San Francisco Bay Area. Any area for which the necessary data are available can utilize the BASS model. The number of subareas used can vary from 1 to 900. The time span of each iteration is completely variable, as is the information in the time-distance matrix. This transferability of the technique to any region is perhaps the model's greatest strength and source of usefulness.

A further possibility worth exploring concerns the inclusion within the model of a trip distribution scheme. This would have the immediate advantage of integrating the land use and transportation forecasts because employment, population, housing, land use, and the related distribution of trips would be presented in one output package. The resultant trip distributions might be more reliable as they would be generated simultaneously with the locational decisions. Similarly, shopping and commuting trips would be generated at the time each household is put in place.

Inclusion of the trip distribution algorithm directly within the BASS model represents a major modification of the BASS model. However, previous experience with the model has shown that the relative independence of the submodels allows great flexibility in programming. Thus, in the past we have been able to include substantial subroutines, not unlike the trip distribution algorithms, with relatively little effort, because such additions can take place largely independently of the existing program. Therefore, the entire model need not be reprogrammed with each modification, even if such modifications are quite extensive and intricate.

SUMMARY AND CONCLUSIONS

This paper has focused on the need for a comprehensive approach to transportation planning that takes account of the interaction between economic, social, and political factors and the transportation system. It has emphasized the effect of transportation on other aspects of the urban environment. This constitutes a feedback or complete interaction between the transportation system and the other system of the metropolitan region.

It is the purpose of this paper to present the reader with the basics of the BASS model and how it can be applied to the transportation planning. To this end, the model, really a series of independent but connected submodels, is sketched out briefly, emphasizing the flexibility that has been incorporated into the model's structure. Having provided the reader with the rudiments of the BASS framework, several suggested uses of the BASS model were presented. The thrust of these suggestions is that the model has sufficient flexibility to supply the much needed feedback from the transportation plan to spatial arrangement of employment and residences in the region. Finally, it is suggested that with suitable modification, the model could be extended to generate trip distributions internally, thus bypassing the use of separate trip distribution algorithms.

After several years of working with the BASS model as an operational tool, the authors are satisfied that the suggestions presented in the preceding are feasible. The model has already been applied to forecasting situations involving open-space planning, and water-resource planning. (Water-resource application was done in conjunction with a larger study undertaken by California State Quality Control Board (7). The use of the

BASS model in open-space planning was completed in the summer of 1968, and the results of this application are forthcoming from the Citizens Committee for Open Space, a nonprofit Bay Area organization.) Its extension to the transportation planning field is a natural one that could only help to serve the best interests of both model builders and the entire community of planners. As we have noted many times in the past (6), the BASS model must be used to be useful. With use comes better data, particularly in the critical areas of time-distances and land uses, and experience of the model's performance. The data and the experience interact to make the model much better and more useful.

The application of computerized simulation models is only in the gestation phase. Only through repeated trials can this body of knowledge hope to mature and make a meaningful contribution to human knowledge and the betterment of the urban environment.

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