A Regional Economic Simulation Model for Urban Transportation Planning

DAVID E. BOYCE and SEYMOUR E. GOLDSTONE, Battelle Memorial Institute, Columbus, Ohio

Forecasts of population and employment for urban transportation planning regions can be prepared using the regional economic simulation model described. The model consists of a set of recursive difference equations describing the demographic and employment sectors of a metropolitan region and its growth. Computer simulation studies on the model enable the testing of alternative assumptions and hypotheses concerning a region's future.

•A BASIC requirement for the preparation of land-use forecasts in urban transportation studies is a set of population and economic forecasts for the planning region. These regional forecasts provide control totals for the small analysis zone forecasts of land use, population, income, and employment. In addition, the regional population and economic analysis provides information on the economic vitality of the metropolitan region that bears directly on the region's need and capability for improving transportation facilities (2; 3, Chap. 2; 12, Chap. 2-3).

During the past 10 years regional forecasts in urban transportation studies have been based mainly on extrapolation of trends or on available forecasts that were adapted for the study. One recent study report (12) states that the land-use forecasting procedures are probably somewhat more refined than the regional population and economic forecasts, which are their basic inputs. As this report points out, most transportation studies have allocated much more effort to forecasting land use and urban travel models than to regional economic analysis. Two notable exceptions to this are the economic forecast prepared by Hoch (7) for the Chicago Area Transportation Study, and the forecasting model developed by Artle (1) for the Oahu Transportation Study.

Several reasons for this past underemphasis of the regional population and economic forecasts come to mind. First, the technical skills required to prepare economic analyses and forecasts have been extremely scarce, even more so than transportation planning skills. Second, the methodology required to produce reliable population and economic forecasts was being developed while transportation planning studies were being completed. Isard's work (9) is representative of the state of development of this methodology during this period. Methods available today are in many respects still unsatisfactory for the requirements of urban transportation planning.

This paper describes a regional population and economic forecasting model potentially useful in urban transportation planning. The model was developed as part of a water resources planning study for a large river basin in the eastern United States (6) and is currently being refined and extended. The study was based on the philosophy that existing knowledge of causal forces should be fully exploited in preparing regional forecasts. The structure of the model is, therefore, based on theoretical concepts as well as empirically verified relationships. The relationships are assembled and integrated to achieve a fairly simple operational model of a regional economy. The model equations are solved in a recursive manner over the planning time horizon; the model is run on the IBM 7094 computer using the DYNAMO compiler developed by Forrester (5) and his associates in the Industrial Dynamics Group at M.I.T.

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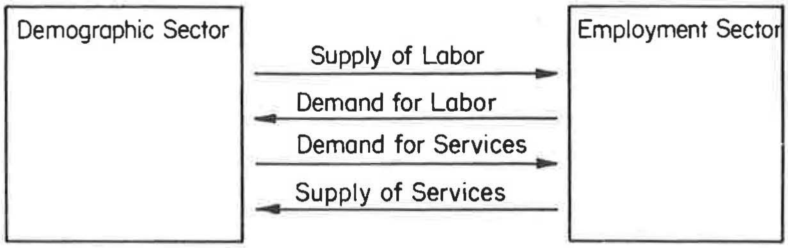

Figure 1. Overview of the model.

The model differs from previous population and economic forecasting procedures used in urban transportation studies in several important respects. First, and possibly most important, the model provides a framework for the planner to test readily the significance of alternative assumptions regarding growth rates and interaction of regional activities without significant model revisions. Second, the model forecasts the path of population and employment growth for the region through time. Most transportation studies have been concerned with a planning horizon 20 to 25 years in the future and have given little attention to the interim period. The model may thus help the transportation planner not only with the question of how much but also the question of when, new facilities should be constructed.

Third, many procedures forecast population as a first step and then either reconcile this forecast with an independent employment forecast or base the employment forecast on the anticipated population level. This model treats population and employment growth as interacting processes (Fig. 1). For example, the growth of employment opportunities will attract migrants to a region, in turn creating new job opportunities in the household-related businesses and services. These interactions between population and employment are an important part of the dynamics of regional economics. The manner in which they are treated can have a significant effect on forecasts.

THE DEMOGRAPHIC SECTOR

The demographic sector of the model is designed to project the level of population and the supply of labor. Changes in population are the combined result of birth, death, and migration rates. Probably, the most important determinant of these rates, as well as the labor-force participation rate, is age. Thus, to trace these demographic variables through time, it is necessary to keep track of the distribution of age of the region's population.

An important question in modeling this sector is, therefore, what kind and how detailed an age breakdown to use. By examining the behavior of birth, death, migration, and labor-force participation rates by age, it is possible to define a set of age groups which is fairly homogeneous with respect to these age-dependent characteristics. Six age groups appear necessary to achieve effective simulation of the population dynamics:

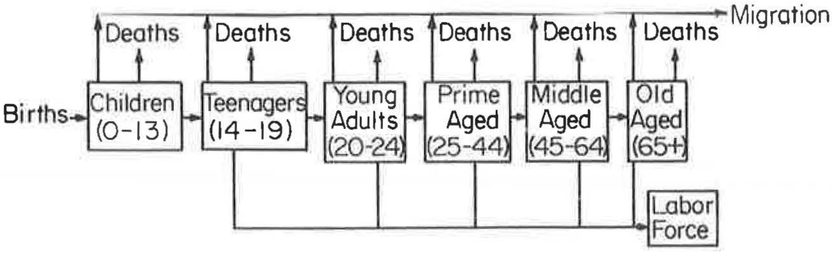

Figure 2. Structure of population flows.

0-13, 14-19, 20-24, 25-44, 45-64, and 65 years and older. Figure 2 shows the basic flows represented in the demographic sector of the model.

Birth and Death Rates

Birth and death rates are fixed for each age group in the current formulation of the model and are based on 1960 regional data. For example, the birth rate for a given age group is estimated as the ratio of live births during 1960 for that age group to total population of the group. There are significant differences, especially for birth rates, among several regions examined. These differences may be explained to some extent by differences in the (a) urban-rural mix, (b) racial composition, and (c) ratio of males to females in the local populations.

Migration

The demographic factor with the greatest potential for wide fluctuation in the short run is migration. In this model, the net migration rate (ratio of in-migration minus out-migration to regional population) for each adult age group is related to relative regional employment opportunities. The regional unemployment rate minus the national rate is used as an index of regional employment opportunities. The migration of children in the model is linked directly to migration of their adult parents.

Figure 3 shows the results of linear regression analyses on net migration between state economic areas in the period 1955 to 1960 (15). These results provide statistical support for the thesis that the 20 to 24 age group is much more responsive to relative employment opportunities than the older age groups. However, all age groups have a net out-migration when employment opportunities are equal.

Coefficients of determination (r^2) also show that relative employment opportunities are more strongly related to net migration for the 20 to 24 age group (0.52) and 24 to 44 age group (0.58) than for the older 45 to 64 age group (0.35). The results for the 15 to 19 age group (0.24) and the retired 65+ group (0.26) are considerably weaker.

Labor-Force Participation Rates

The two important determinants of labor-force participation rates (i.e., rates the labor force to population) are age and sex (17). Since the model does not break down the population by sex, it is assumed as a first approximation that the proportion of

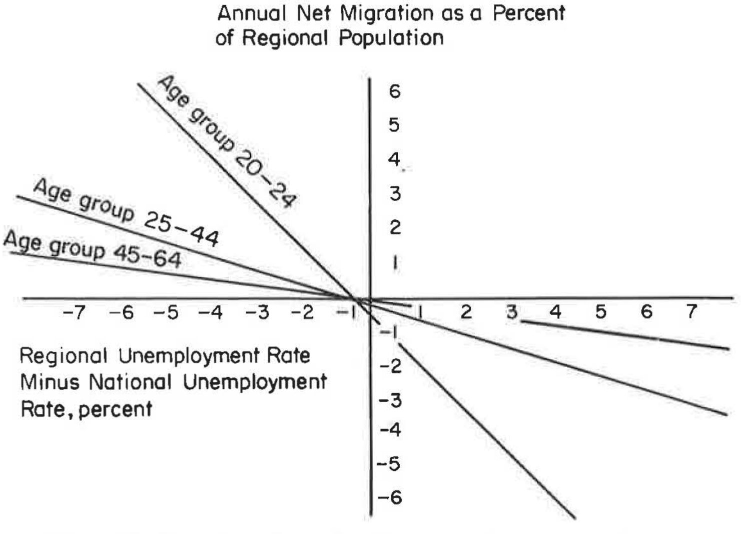

Figure 3. Net migration related to unemployment rate by age.

females in the population will tend to remain relatively constant. This being the case, participation rates are estimated by aggregating over sex for a given age group. Data on participation rates show that age does not explain all the variation in participation rates. In some cases considerable differences exist for given age groups for selected regions. These differences may be attributable to such factors as degree of urbanization, average level of educational attainment, average earning levels, and employment opportunities.

THE EMPLOYMENT SECTOR

Briefly, employment is of two types—provision of goods and services within the region and production for export out of the region. Locally based employment is a function of demand for goods and services by households, local businesses, and manufacturing firms. Employment for export production is a function of the region's competitive advantage or disadvantage with respect to other locations for industry and is measured by comparative indices of wages and access to markets and raw materials outside the region. The employment sector is interrelated with the demographic sector through the regional unemployment rate and population level.

Definition of Employment Types

Export employment is defined as production for sales primarily to nonlocal markets; export producers include both final producers and intermediate producers selling to firms that are producing for sales outside the region. The basis for the export employment forecast is a cost-oriented location model. Therefore, employment in noncost-oriented industries such as some installations of the Federal Government, higher education, and military service are forecast outside the model framework. Similarly, employment forecasts for resource-oriented industries such as mining and agriculture are prepared outside the model and entered as direct inputs to the model.

The second category of employment is designated "local serving" in the sense that goods and services produced are consumed within the region. This employment group serves both household demands for goods and services in the region and requirements of local firms for goods and services of a generalized type such as transportation, communication, and public utilities.

General knowledge of industry shipment patterns and results obtained in previous research (4, 10, 13) provide a basis for classifying industries into the two types. In general, production of goods and services for sales to the region's households and all types of firms in the region is the criterion used to distinguish local serving from export employment. This definition results in all 2-digit SIC manufacturing industries (Standard Industrial Classification Numbers 20 through 39) being classified as export, with several important exceptions. Those manufacturing industries whose products are produced entirely for local consumption, such as dairy products, newspapers, bakery products, commercial printing, public utilities, and construction materials, are removed from the export classification and designated as local serving employment. All other industries, including SIC Numbers 40 through 89, are classified as local serving.

The Export Employment Model

The forecasting equations for location and growth of export employment in the region may be viewed as a simple adaptation of industrial location theory to the forecasting model. Industrial location theory, as formulated by Isard (8) for example, embodies the concepts of market area, source of raw materials, transportation costs, and local production costs including wages. The procedures for incorporating these concepts into the forecasting model are now described.

Consider a group of manufacturing industries with similar transportation costs, labor requirements, and market-area characteristics. The market area for these industries may be defined from data on shipping characteristics such as is available from the U. S. Census of Transportation (16). For example, a typical market area might be those states east of the Mississippi River for a metropolitan region located in the eastern United States. Industry growth rates for the total market area by 2-digit manufacturing industries are available from the national and state projections to 1976 by the National Planning Association (11).

This market area growth rate is used as a starting point for the computation of a regional growth rate. The region's industry growth rate, as contrasted with that of its market area, is determined by its relative advantage with respect to costs incurred in manufacturing and distributing the product. A cost index is formulated which compares the region's total costs with the costs of other regions serving the same market area. Costs that vary significantly between regions are wage costs and transportation costs for both raw materials and products. Wage costs are adjusted during the operation of the model in response to the local employment conditions. Transportation costs also may be varied during the model operation to incorporate major changes in the transportation system such as the construction of an Interstate highway.

The cost index operates in the following manner. If the region offers lower cost characteristics than competing regions in the market area due to lower labor costs or better access to market and raw materials, then a regional industry growth rate greater than the corresponding market area growth rate is inferred. However, if the access characteristics of the region or its labor costs are higher than in competing areas resulting in a cost index greater than 1.0, then the industry growth rate is adjusted downward accordingly. A cost index equal to 1.0 means that the industry growth rate for the market area also applies to the region.

In the applications of the model to date, export employment is divided into four industry groups with similar labor and transportation cost characteristics; two of the groups are fabricating industries and two are processing industries. Market areas, wage costs, and transportation costs are defined and derived for each of these four industry groups, and regional growth rates are computed for each industry group.

Local Serving Employment

Local serving employment is divided into two subcategories, household serving and business serving. First, household-serving employment, which includes all employment primarily engaged in production of goods and services for sale to households, is forecast as a linear function of regional population. Analysis of the relation between total regional population and household-serving employment in several metropolitan

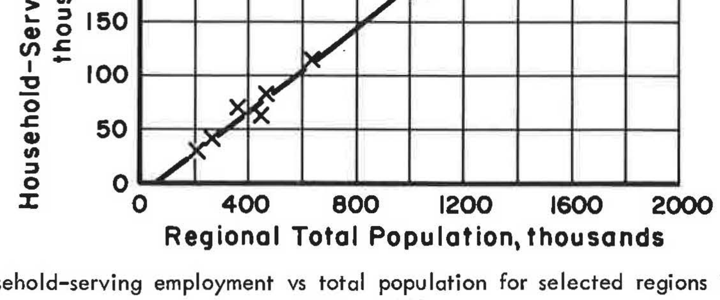

Figure 4. Household-serving employment vs total population for selected regions in eastern United States, 1960.

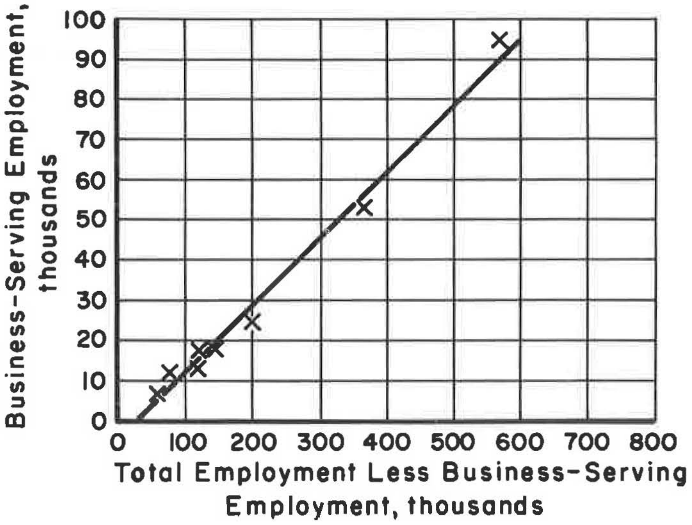

Figure 5. Business-serving employment vs total employment less business-serving employment for selected regions in eastern United States, 1960.

regions in the eastern United States indicates a satisfactory relationship (Fig. 4). Business-serving employment, which includes all employment engaged in the production of goods and services for sale to firms in the region, is related to all other employment in the region in a similar manner (Fig. 5).

INTERRELATIONSHIPS BETWEEN EMPLOYMENT AND DEMOGRAPHIC SECTORS

The key variable in the interaction between the employment and demographic sectors is the local unemployment rate. Unemployment rate is determined by the combined forces of labor supply from the demographic sector and labor demand from the employment sector, and it in turn affects both these sectors. The path of causality is shown

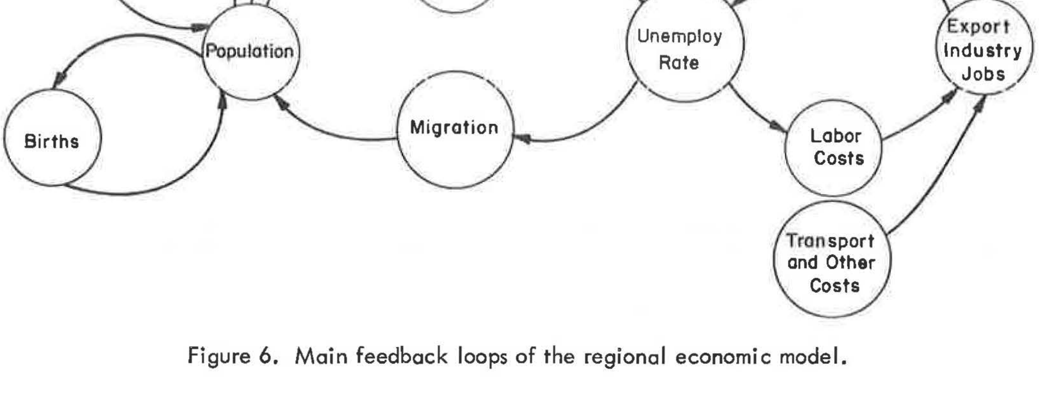

Figure 6. Main feedback loops of the regional economic model.

in Figure 6, depicting the main feedback loops of the model. A second important interrelationship (Fig. 6) concerns the requirements for goods and services in the household-serving industries, which are related directly to population. Employment in this category in turn affects the demand for employment in the business-serving industries. With these interactions in mind, the next section describes how the regional economy evolves over time.

MODEL DYNAMICS: SENSITIVITY ANALYSIS

One of the major advantages of using a computer model for making economic forecasts is that it is a very simple matter to test the effect of changing assumptions. This testing for sensitivity of various parts of the model is important during both the model formation and the model use stages. During the model formation period, various simplifying assumptions are invariably made. The planner will have less supporting evidence for and less confidence in some of these assumptions than others. Therefore, he will vary these assumptions to see if the conclusions are sensitive to them. Sensitive and insensitive parts of models can thereby be pinpointed and the information used for guiding further model refinement.

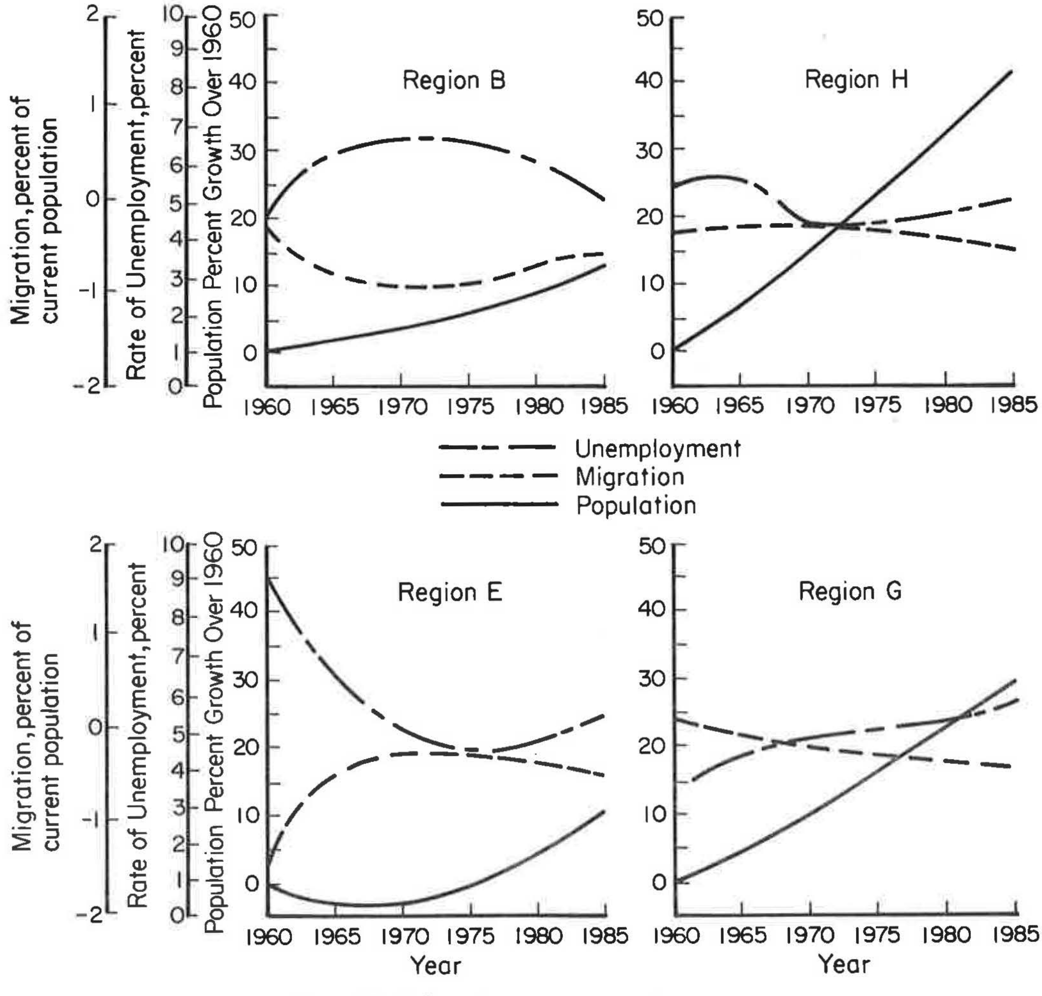

Figure 7. Selected percentage projections.

In keeping with this research strategy, sensitivity experiments are made as a regular part of the research process. Two sets of these experiments, one on migration and the other on skills, are discussed. First, however, it will be helpful to examine several typical model runs. Figure 7 shows typical model output for population, migration, and unemployment rate for selected regions. These graphs show that the model is capable of producing different patterns for different regions. These different patterns arise from differences in initial imbalances between jobs and labor force, differences in the initial mix of export industries, and in enduring differences in competitive advantages due to different locations.

In Region B, because of a failure of jobs to grow fast enough, unemployment rate rises over the first decade. Because of the lack of job opportunities the model generates increased out-migration and reduces pressure for wage increases. This combination of forces results in a decline in labor force growth rate which coincides with increased growth in jobs (because of stable labor costs). A downward correction in the unemployment rate results, slowing out-migration and causing toward the end of the 25-yr period, an increase in the rate of population growth. Examination of the patterns generated for the other regions represented in the diagram will reveal similar forces at work.

Sensitivity Experiments on Migration Formulation

One interesting set of sensitivity experiments concerns tests of various assumptions about the migration formulation. As discussed in the migration section, a statistically significant linear relationship exists between net migration and unemployment rate. We believed that additional research could improve on the accuracy of these results.

However, further expenditures on this part of the model could be justified only if it was sensitive. To determine this, several runs were made in which different relationships between migration and relative unemployment were tried. Figure 8 shows the migration line for the 20-24 age group for three of these runs. The relationships for the other unemployment-dependent migrating groups (14-19, 25-44, 45-64) were changed in similar ways. Run 42 used the relationship drawn directly from the statistical results and thus serves as a basis for comparison against the other runs in this series.

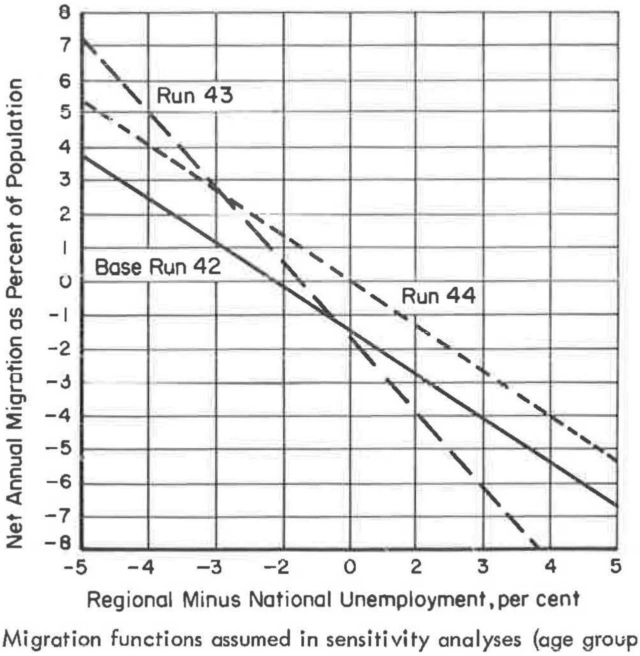

Figure 8. Migration functions assumed in sensitivity analyses (age group 20-24).

TABLE 1

RESULTS OF SENSITIVITY ANALYSES OF MIGRATION FUNCTIONS

Simulation Run[a]	Characteristics of Migration Line	Population Growth Relative to Base Run After 25 Years
42	Migration line based on statistical analysis, so that region has out-migration even when local equals national unemployment	Base Run
43	Slope of migration line doubled	100.3%
44	Migration line shifted upward so that no out-migration occurs when local equals national unemployment	106.8%

[a]Numbers correspond to computer simulation identification system used internally by research group.

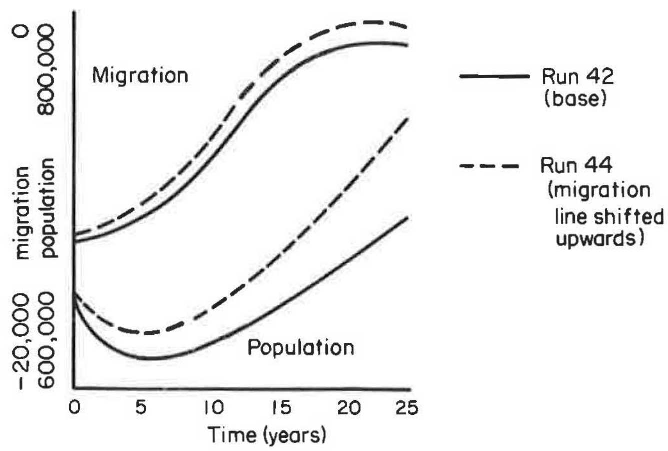

Figure 9. Run 44 superimposed on Run 42.

In Run 43, the slope of the migration line was doubled (Fig. 8). In this run, the initially high unemployment causes more out-migration from the area than in the base run. However, this reduces the labor force, thereby lowering the unemployment rate, resulting finally in less out-migration. Thus, despite doubling the slope of the migration line, population growth over the 25-yr period in this run is almost the same as that in the base run.

Run 44 examined the effect of an upward shift in the migration line (Fig. 8) such that no migration occurs when the local unemployment rate equals the national average. In this case the region grows somewhat more rapidly (Table 1).

Figure 9, a graph of population and net migration of Run 44 superimposed on the base Run 42, illustrates what is happening here. Two factors in particular are combining to cause an increasing divergence in the population projections. First, the migration line is shifted upward, resulting in a reduced net outflow of people. Second, the upward shift in the 4 migration lines to pass through the origin mainly affects the young 20-24 age group (see Fig. 3). Thus, in Run 44 the area is not only losing fewer people but is losing fewer people in the age group which has the highest reproduction rate. Therefore, a higher natural rate of population increase is combined with a higher net migration rate, leading to an increasing divergence in the population projections.

The conclusion drawn from these sensitivity experiments is that the projections are insensitive to changes in the slope, but at the same time somewhat sensitive to changes in the intercept. As a consequence, additional statistical analysis has been undertaken on migration.

Sensitivity Experiments on Skill Level

There is a growing awareness and concern about the effects of education and skill level of labor on regional economic vitality. Unfortunately, in treating a variable such as skill level the investigator is confronted with measurement difficulties. Despite this lack of measurable cause and effect, we introduced several speculative hypotheses involving skill level. The purpose was to determine if regional growth is sensitive enough to this factor to justify the considerable additional exploration that may be needed to refine and test such hypotheses.

After considerable deliberation, despite the recognized limitations, we decided to use educational attainment as a measure of skill level. This is based on the idea that education increases the trainability and thus the potential skill a worker can achieve.

Available data also show that educational level affects the migration rate (Table 2). The migration rate is substantially the same for people who have a high school diploma or less, whereas those with some college education migrate more frequently. The effect is particularly dramatic for the younger 25-44 age group.

TABLE 2

RELATION BETWEEN EDUCATION LEVEL AND MIGRATION RATE BY AGE

Years of School Completed	Migration Rate	
	25-44 Age Group	45-64 Age Group
0-7	5.2	2.9
8	5.7	2.3
9-11	5.8	2.6
12	5.2	3.0
13+	10.7	3.5

Source: U. S. Department of Commerce, Bureau of the Census, Current Population Reports, Series P-20, No. 127 (January 15, 1964): Mobility of the Population of the United States, April 1961 to April 1962, Table B, p 4.

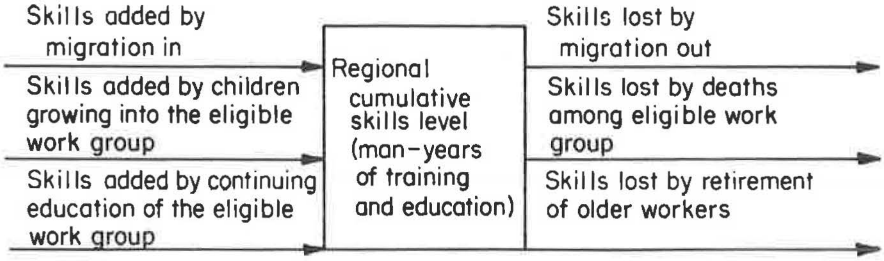

Figure 10. Influences on cumulative skills level.

TABLE 3

SENSITIVITY ANALYSES OF SKILLS EFFECTS ON RELATIVE WAGE COSTS AND MIGRATION

Simulation Run[a]	Characteristics of Skills Effects on Relative Wage Costs	Population Growth Relative to Base Run After 25 Years
47	None	Base Run
62	Relative skills inversely related to relative wage costs	102.6%
63	Same as Run 62, except trend in national skills retarded relative to region	117.1%
76	Migration directly related to skill level	107.1%

[a]Numbers correspond to computer simulation identification system used internally by research group.

Model Formulation of Skills.—In the model, the total skill level of the region's population is represented as the cumulative man-years of education and training of all people in the region in the age range of the labor force (14-64). To the cumulative man-years existing at the beginning of the forecast period are added those brought in by children growing up into the labor-force age group, by migrants into the region and by the continuing education and training of those over 14 years old. Lost from the region's cumulative skills are those withdrawn because of deaths and outward migrations among the "eligible" work group (age 14-64), and retirement of older people from the labor force. The factors modifying the overall cumulative skills level are shown in Figure 10.

In modeling the skills added by entry of the young into the eligible work group, the character of compulsory education is noted so that all youths becoming 14 years old are regarded as having completed 8 years of education. Education beyond the age of 14 is represented in 1960 as adding 3.6 years of education and training to every teenager and trended to 1985 to provide 4.8 years beyond the age of 14. Thus, it is assumed that the average 1960 teenager will receive 11.6 years of education and training, whereas the average 1985 teenager will receive 12.8 years. Such a trend appears reasonable, but variations of this trend have also been tested.

Sensitivity Experiments on Skills Formulation.—Three of the sensitivity experiments conducted on skills are reported here (Table 3).

In Run 76 a relationship between migration and skill level was hypothesized, roughly on the basis of Table 2. According to this hypothesis, as the average skill level in an area increases, the migration rate is modified by an effect of skill index (ratio of regional migration rate to migration rates occurring at average national skill level, Fig. 11). After 25 years this leads to a population projection 7 percent greater than the projection in the base run. This occurs because the region starts out with a relatively low skill level, resulting in a lower rate of out-migration and consequently a greater number of births than in the base run. These two effects combine to produce the higher population projection.

In Run 62 a relationship between relative skills level and relative wage costs was hypothesized. According to this hypothesis, a region with higher average skills level has more productive labor and hence can supply more labor output per dollar wage, thereby cutting total wage costs (Fig. 12). A very small but positive effect occurred due to the growth of skills in the region at a slightly higher rate than the national average.

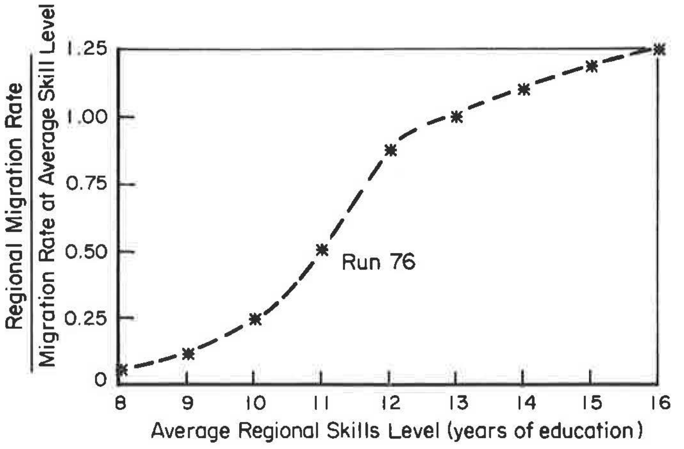

Figure 11. Migration related to average regional skills level.

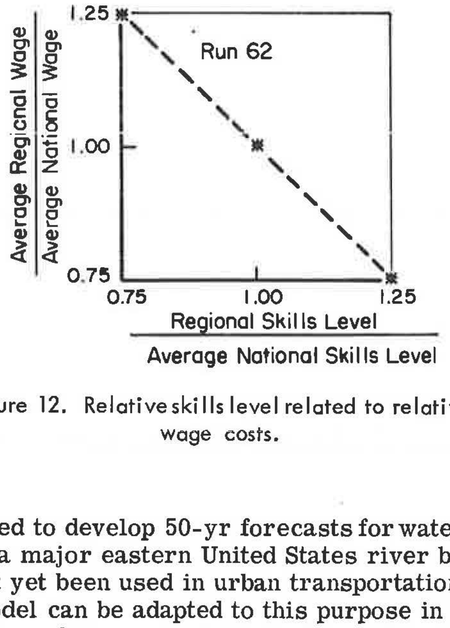

Figure 12. Relative skills level related to relative wage costs.

Run 63 shows the potential of increasing regional growth by accelerating skills development. In this run the region was allowed to outstrip the national average in the education and training of its population. The impact was quite large in 25 years (17%). Moreover, the effects of such skills buildup are cumulative and ever-increasing. These sensitivity experiments clearly indicate that skills level may have extremely important effects on regional economies. Assumptions made about skills do, therefore, significantly affect medium- and long-run projections.

CONCLUSIONS

The regional economic forecasting model described above has been successfully applied to develop 50-yr forecasts for water-resources planning for 8 contiguous regions in a major eastern United States river basin. Although this forecasting technique has not yet been used in urban transportation studies, ongoing research indicates that the model can be adapted to this purpose in a straightforward manner. Several characteristics of the model indicate the utility of this approach for regional forecasting:

1. The explicit form of the forecasting methodology facilitates evaluation and use of the forecasts.
2. The use of a simulation compiler in the computer operation of the model essentially eliminates computer programming and facilitates experimentation with the model.
3. Low computer operating cost makes feasible the testing of alternative growth rates, parameters, and formulations so that an entire set of forecasts based on alternative assumptions and submodels may be prepared.
4. Updating the forecast as the model is revised or new data becomes available requires only a rerun of the model.

As with many operational forecasting techniques, model development is never entirely completed. Ongoing research studies are revising and extending the model described in this paper. Of particular importance for transportation planning is the incorporation of a regional income forecast into the model, from which may be derived the vehicle ownership forecast. The export employment sector is being reformulated in an attempt to incorporate recent research findings on the movement of investment capital among regions. The problems of migration rates and labor force participation rates are being restudied in light of recent developments in this research area. These model improvements may be expected to provide, overtime, a forecasting capability at least commensurate with the status of land use and trip forecasting models for urban transportation planning.

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