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AUTHOR Dei Rossi, J. A.; And Others
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ABSTRACT

This report presents the results of the implementation in the State of Illinois of a methodology for analyzing the relationships between health education and health manpower supply, and the relationship between supply and service, specifically in the field of dentistry. The major findings show that: (1) in analysis of the geographic distribution, there is a significant variation in the distribution of dentists relevant to the population; (2) increasing the productivity of dentists is a potentially powerful way to increase service availability; (3) the number of full-time equivalent dentists per 100,000 will increase gradually and slightly by 1980; and (4) the growth of dental manpower supply in the state will only keep pace with population growth despite significant planned increases in dental manpower training. (HS)

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An Analysis of Dental Manpower and Education in Illinois

J. A. Dei Rossi, J. E. Eckles, P. D. Fleischauer,
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A Report prepared for

HEALTH EDUCATION COMMISSION OF THE ILLINOIS BOARD OF HIGHER EDUCATION

Rand
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PREFACE

Early in 1970, The Rand Corporation was asked to assist the Illinois Health Education Commission (HEC), an advisory body to the State Board of Higher Education, by developing a methodology for generating better information for health manpower education planning. One important part of this work dealt with the problems of analyzing manpower supply as it relates to educational plans and manpower requirements.

This report describes the first of a series of studies, each concerning a particular category of manpower. Dentists were chosen as the first category to test the methodology and to illustrate the value and problems of comprehensive manpower analysis, partly because of data considerations and partly because of the analytical characteristics of dental manpower. From a data point of view, there was enough information available on dentists for analysis. Further, dentists require sufficient training and are sufficiently important from a health care point of view to make them an interesting category from a health manpower education planning point of view. Finally, they could be studied without necessitating deep involvement in the health care system, and reasonably acceptable measures of activity and output were available.

This report, therefore, emphasizes the methodological issues, problems of implementation, and value of the research. The studies of the other categories were applications of the same basic methodology and were reported on to the HEC in informal working notes. These categories included: Optometrists, Pharmacists, Podiatrists, Physicians (MD's and DO's), Registered Nurses, and Veterinarians. The major determining factor for inclusion was data availability. Even among this limited set of categories, the quality of the data is quite uneven.

The study is of value to health planners primarily because it develops a comprehensive structure for bringing together data in such a way as to permit the analysis of the relationships between educational output and supply as well as the relationship between supply and service availability. Because of the breadth of the approach, it is necessarily first level in the sense that, although the methodology is complete, the estimation of many of the important variables affecting supply and its adequacy is not treated extensively. However, the methodology allows the users to examine the quantitative importance of most of these variables, thus providing both immediate results and important information for the direction of future research.

SUMMARY

This report presents the results of the implementation of a methodology for analyzing the relationships between health education and health manpower supply, and the relationship between supply and service. It is the first in a series of studies done for the Health Education Commission of the State of Illinois and, therefore, emphasizes methodological issues.

The study of dental manpower begins with a careful analysis of the current (1969 year end) supply. It is found that, adjusting for expected age-related activity rates, the estimated number of full-time equivalent (FTE) dentists is substantially lower than the nominal supply: 4586 vs. 6676.

Analysis of the geographic distribution of these dentists shows that there is a significant variation in the distribution of dentists relative to the population. For example, to bring all the counties up to the state dentist-to-population ratio of about 45 dentists per 100,000 population, even assuming the dentists could be placed only in counties below the average, would require about a 10 percent increase in the number of dentists.

The study also shows that increasing the productivity of dentists (by increasing the use of auxiliaries, for instance) is a potentially powerful way to increase service availability. A 10 percent increase in productivity would reduce the number of dentists required to bring all counties up to the state average by about 30 percent.

The base-line projection of future supply, using current educational plans, estimates that the number of FTE dentists per 100,000 will increase gradually and slightly by 1980. As an alternative, if no increases in dental education over the current level occurred, the ratio would decrease.

These estimates are predicated on the stated rates of migration, retirement, and death. Migration and retirement factors are areas that require further research, but the methodology described provides a structure for analyzing the relative importance of these, thereby providing useful information for the direction of future research.

Aside from the methodological development described, the major finding of the study is that under reasonable assumptions (based on limited historical data), the growth of dental manpower supply in the state will only keep pace with population growth despite significant planned increases in dental manpower training.

ACKNOWLEDGMENTS

The authors are indebted to various individuals for data, information, and assistance in the preparation of this report. In particular, we wish to acknowledge the contributions of James N. Ake, Donald W. Johnson, and Roger Cole, all of the Division of Dental Health, U.S. Public Health Service; and B. Duane Moen, Thomas Ginley, and Victor Smith of the American Dental Association (ADA), who were especially helpful in furnishing the Illinois ADA membership records and other pertinent data. Also, we would like to acknowledge the assistance of W. J. Greek of the Illinois State Dental Society, B. J. Crawford of the American Association of Dental Examiners, and the deans of the dental schools in Illinois who provided data through the Illinois Health Education Commission.

CONTENTS

I. INTRODUCTION

The Health Education Commission (HEC) of the State of Illinois is an advisory body to the State Board of Higher Education (BOHE). The HEC was organized as a result of a survey of health education in Illinois that recognized "a need for mobilizing and coordinating the widely diverse resources within the State toward the production of health care manpower."* The Rand Corporation is assisting the HEC by developing an initial analytical framework that can be further developed and used by the HEC on an ongoing basis. This includes the formulation and initial implementation of methodology for health manpower analysis, health manpower education cost analysis, and information system design.

This paper on dentists is the first of a series of studies on particular categories of health manpower. The emphasis is on the supply aspects rather than the demand aspects. The major focus is on the relationship between educational output and supply, since the study is intended primarily for use by educational planners.

There are, of course, many other factors, in addition to educational output, influencing both the supply of manpower and its value in the provision of health care service. These include migration in and out of the state, intrastate location of health manpower relative to the location of population, and the productivity and degree of activeness of the manpower pool. However, given the need of the HEC for coverage of a fairly broad spectrum of manpower categories, time and data limitations, and the fact that the primary policy variable of the HEC is educational output, emphasis was given to analysis of the role of the educational system and the impact of changes in educational output on supply.

In practice, this has meant that limited attention has been given to analyzing the forces influencing the other three major factors affecting supply. Instead, a general model including variables representing these factors has been developed that can be used by the HEC to explore the importance of these factors and, thereby, provide both results

*_Education in the Health Fields for State of Illinois_, Vols. 1 and 2, Board of Higher Education, Springfield, Illinois, June 1968.

of immediate usefulness and information on the relative importance of these other factors. This information provides important guidelines for future research in this area.

The study begins with the estimation of the number of full-time-equivalent (FTE) dentists in the state at year end 1969. A dentist count obtained from the American Dental Association was used as the primary data for these calculations. The records did not have valid data on retirement or amount of time practiced per year. To obtain estimated FTEs, the total number was first adjusted for expected retirement based on the age distribution, and then converted to FTE by adjusting for the average expected number of visits in each age category. These adjustments reduced the nominal number of 6676 dentists to 4586 FTEs. This reduced the nominal state-wide dentist-to-population ratio of 60.2 per hundred thousand to an FTE-to-population ratio of 41.4 per hundred thousand.

In the following section, the basic methodology of manpower requirements analysis used in the study is described and illustrated with 1969 data. Three major population variables are included: population size, geographic distribution, and mobility in seeking care. To handle the mobility problem two cases that approximate the upper and lower bounds of patient mobility are introduced. In the first, it is assumed that no person leaves his own county for service. In the second, it is assumed that the population in each county optimally uses the dental manpower in all adjacent counties. The analysis shows that to bring all the counties of the state up to the national average of 1.3 annual visits per person would require from 220 to 280 additional FTE dentists. To bring all the counties up to the national average of 2.3 visits per person for families who had annual incomes over $7,000 would require about 2400, or about a 52 percent increase.

These calculations were based on the assumption that additional dentists would distribute themselves as required in the deficit areas. This is a most optimistic assumption. If one assumes that the additional dentists distribute themselves in proportion to the current dental population, estimated requirements are significantly increased. As an example, assuming an optimum distribution of dentists, the number needed to bring all counties up to the state average of 1.5 visits per year is from 440 to 480 additional FTE dentists. If a proportional distribution is assumed, the 440 to 480 "vacancies" imply a need for about 2600 dentists. Neither assumption is considered completely accurate, but the examples illustrate the importance of the geographical distribution of dental manpower.

A third important factor, in addition to altering the number and distribution of dentists, is productivity. An FTE dentist has been defined in terms of the national average of 3629 visits per year. Relatively small changes in productivity can have a strong impact. For example, at a level of 1.5 visits, a 10 percent increase in productivity reduces the number of "vacancies" from about 450 to about 300, a decrease of one-third.

The supply forecasting procedure is also illustrated, using the 1969 supply as a point of departure, and future supply is forecast on the basis of projected educational output. A mathematical model (the supply equation) estimates the effects of the processes that operate to effect changes in supply. These processes are graduation, migration, retirement, and death. Productivity and geographical distribution are used only in analyzing the service implications of a given supply. A student flow model projects future graduate streams, relating future enrollment and graduates to expected new registrations through the use of retention rates calculated on the basis of past experience. Migration rates are also based on past experience.

Forecasts of the future Illinois supply of FTE dentists show the impact of projected new registrations on enrollment, graduates, and supply. Using planned enrollments as a base-line case, the supply of FTE dentists is estimated to increase 56 percent from 1970 to 2000; when estimated population increases are accounted for, the dentist-to-population ratio is expected to increase only about 13 percent in the same period. As an alternative plan, if enrollments are held constant at 1970-71 levels, the supply of dentists relative to population decreases steadily throughout the period.

Given estimates of future supply, the question of interest is how they compare to future requirements. Examination of this question is based on the assumptions that the current supply remains in the same location throughout the forecast period and that new dentists distribute themselves among counties in the same proportion as the current supply. Unless there is a change in the level of care demanded, only small changes in the dentist deficit are expected to occur: At 1.5 visits per person per year, the deficit is 450 in 1969, 530 in 1980, and 590 in 1990. Although the overall ratio is improving over time, imbalances in the distribution cause slightly larger deficits to occur. If demand increases to 2.02 visits per person per year in 1980, based on a relationship between demand and mean family income, the deficit becomes 1700 FTE dentists and results in a 25 percent deficit in the number of visits provided. Use of this relationship for 1990 results in a demand level of 2.3 visits per person per year, causing a deficit of 2600 FTE dentists and a 29 percent service deficit. Although the relationship between demand and mean family income is by no means a definitive one, rising incomes and other factors will no doubt increase the demand for dental care in the future.

The results of this study indicate that the planned increases in dental enrollment and graduates will do little more than keep pace with population growth. Any increases in the level of care demanded will result in significant deficits. Meeting these deficits by enrollment or migration changes alone would require large increases, on the order of doubling the future graduate stream or doubling the percentages of new graduates who practice in Illinois. An alternative is to increase productivity by altering the delivery of dental care. An experiment has indicated that use of four expanded-function auxiliaries can increase a dentist's productivity (in terms of patients seen) by about 40 percent.* In 1980, at 1.5 visits per person per year, increasing dentist productivity by 40 percent reduces the dentist deficit by about 80 percent, from about 500 to about 100. Of the several approaches to meeting future demands for care, no single approach is likely to be sufficient in itself; Illinois planners and policymakers will probably have to rely on a mix of many methods to meet rising demands for dental care.

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*S. Lotzkar, D. W. Johnson, and M. B. Thompson, *Experimental Program in Expanded Functions for Dental Assistants*, U.S. Department of Health, Education and Welfare, Bethesda, Maryland, in preparation.

II. ILLINOIS DENTAL MANPOWER 1969

This section contains estimates of the total year-end FTE dental manpower pool in the state of Illinois and the county-by-county distribution of these FTEs. The estimates are made by adjusting the nominal number of dentists for retirement and standardizing on the basis of the expected number of visits per year. These FTEs are then used as a basis for calculating manpower requirements and status as a function of dentist-to-population ratios and service levels, measured in terms of available visits per person per year. It should be pointed out, however, that due to the relatively large population of dentists over 65 listed in the Illinois records, relatively small variations in the retirement rates used can cause significant differences in the estimate of the number of FTE dentists. Thus, the FTE estimates should be considered approximations subject to adjustment, given more accurate information on retirement of dentists in Illinois.

QUANTITY OF DENTISTS

There is, at present, no accurate source of data with which to calculate the number and distribution of practicing Illinois dentists. It appears that the best approximation can be obtained currently from the American Dental Association (ADA) membership records, which are available in machine-processable form.* The ADA membership records include the great majority of dentists (approximately 90 percent) in Illinois and a substantial portion, if not all, of the nonmember dentists. The initial count of Illinois dentists listed in the ADA records was 6676. In computing the FTEs, only those dentists whose records indicated association with the delivery of care to the civilian population were included. Thus, dentists in the military service, dentists engaged in other occupations, or students were not considered.

The difficulties in using the current ADA records for the purpose

*Most of the Public Health Service statistics concerning the number of practicing U.S. dentists are based on these records, which were supplied to us through the courtesy of Victor Smith of the American Dental Association.

of manpower assessment arise because these records have been designed primarily for other purposes, including journal distribution and dues collection. Thus, the ADA records provide little information concerning the extent and amount of patient care that is being provided by members. For example, there is no indication on a member's record of whether he currently practices full or part time. Retirement information, although available, appears to be inaccurate. In particular, the 1969 records indicate that 22 percent of the Illinois dentists are over 65 years of age, although only approximately one-half of 1 percent are listed as retired.

Despite these deficiencies, the Illinois ADA records do provide basic data from which it is possible to make inferences concerning the average (or expected) amount of dental care provided. For each dentist, the records give his age, address, year of graduation, school, specialty, military service, and type of membership. Although the knowledge of a particular dentist's age does not reveal the percentage of time he devotes to patient care, it does contain this information in the aggregate; that is, it is possible to say that on the average, X percent of the dentists aged 65 are retired, or, on the average, a 65-year-old dentist has Y patient visits a year. It is this kind of statistical information that allows one to transform the count of dentists as given by the ADA records into numbers of FTEs.

In order to make this transformation, statistics of dental practice as given in *The 1968 Survey of Dental Practice** have been applied to the Illinois ADA records. Using the results of the 1968 survey, the fraction of dentists expected to be retired at each age has been computed and is as follows:

	Expected Fraction Retired
Under 50	.000
54	.012
59	.052
64	.337
69	.823
74	.972
75 and over	1.000

*American Dental Association, Bureau of Economic Research and Statistics, *The 1968 Survey of Dental Practice*, Chicago, 1969.

These retirement figures are based on the anticipated retirement age as given by the dentists surveyed who were between 50 and 59 years old.

To obtain a measure of how much patient care is delivered by a dentist, the average number of patient visits for each age bracket, as given by the survey, is divided by the average number of patient visits for all ages, 3629 visits per year. The resulting factors for each age bracket are as follows:

	Fraction of FTE
Under 30	.752
30 - 39	1.032
40 - 49	1.103
50 - 59	.969
60 - 69	.626
70 and over	.620

The performance of 3629 visits per year thus corresponds to a factor of 1 and is considered to represent one FTE dentist.

By taking the product of the activity factor (one minus the expected fraction retired) and the corresponding FTE factor for each age bracket, we obtain a new set of factors that gives the expected FTE of a randomly selected dentist in each age bracket as follows:

	Fraction of FTE
Under 30	.752
30 - 34	1.032
35 - 39	1.032
40 - 44	1.103
45 - 49	1.103
50 - 54	.956
55 - 59	.919
60 - 64	.416
65 - 69	.111
70 - 74	.017
75 and over	.000

In other words, these factors represent the average FTE that one would expect to obtain by observing a representative sample of dentists. Thus, although these factors may not be accurate when applied to a single dentist, they are approximately correct when applied to a population of dentists.

The result of applying the factors to the 1969 Illinois ADA records reduces the number of dentists from a nominal 6676 to a total of 4619 active dentists (not retired) or 4586 FTEs. The corresponding number of estimated FTEs by county is shown in Table 1.

Table 1

FULL-TIME EQUIVALENT DENTISTS BY COUNTY, 1969[a]

County	*FTE*	*County*	*FTE*	*County*	*FTE*	*County*	*FTE*
Adams	22.5	Ford	5.2	Livingston	9.2	Putnam	.2
Alexander	1.6	Franklin	8.5	Logan	8.7	Randolph	7.1
Bond	3.1	Fulton	6.8	McDonough	9.9	Richland	5.9
Boone	6.3	Gallatin	1.0	McHenry	52.2	Rock Island	53.7
Brown	1.2	Greene	3.2	McLean	39.4	Saint Clair	66.8
Bureau	12.9	Grundy	10.9	Macon	42.4	Saline	10.1
Calhoun	.0	Hamilton	1.6	Macoupin	15.0	Sangamon	62.4
Carroll	3.9	Hancock	5.9	Madison	85.0	Schuyler	1.0
Cass	4.6	Hardin	1.0	Marion	15.2	Scott	.2
Champaign	62.2	Henderson	.0	Marshall	5.5	Shelby	2.7
Christian	8.5	Henry	13.7	Mason	4.2	Stark	.2
Clark	2.0	Iroquois	7.4	Massac	1.8	Stephenson	22.4
Clay	2.7	Jackson	19.1	Menard	1.7	Tazewell	43.8
Clinton	5.4	Jasper	4.7	Mercer	2.0	Union	3.1
Coles	17.6	Jefferson	9.7	Monroe	4.1	Vermilion	29.0
Cook	2645.9	Jersey	2.5	Montgomery	5.4	Wabash	2.1
Crawford	5.7	Jo Daviess	4.3	Morgan	15.6	Warren	6.8
Cumberland	.2	Johnson	.6	Moultrie	3.8	Washington	3.8
De Kalb	17.5	Kane	124.2	Ogle	13.1	Wayne	1.8
De Witt	2.8	Kankakee	28.9	Peoria	66.7	White	3.6
Douglas	6.4	Kendall	4.3	Perry	4.2	Whiteside	20.0
Du Page	261.6	Knox	19.4	Piatt	2.8	Will	76.8
Edgar	8.4	Lake	182.9	Pike	3.9	Williamson	11.3
Edwards	3.0	La Salle	43.0	Pope	.7	Winnebago	90.7
Effingham	9.2	Lawrence	4.1	Pulaski	.0	Woodford	7.2
Fayette	3.7	Lee	9.8				

[a]State total = 4586.3.

MANPOWER REQUIREMENTS

Although little can be done in the short term to affect the number and distribution of dental manpower in the state, it is useful to begin with an analysis of the current situation: Better data are available to illustrate the basic methodology and the current status provides a baseline against which changes can be compared. For the purpose of this analysis, dental manpower requirements are expressed in terms of the total number of dentists and their geographic distribution. Obviously, further specification, such as area of specialty and use of auxiliaries, would be interesting but difficult considering the nature of current data sources and the fact that the great majority of dentists are now general practitioners. In determining dental manpower requirements, many factors could be brought into consideration. Some have to do with the magnitude of the population to be served and its aggregate properties. Others concern the individual characteristics of the population as they affect demand or need for dental services. In this study we shall consider only three population variables: population size, distribution, and mobility in seeking care. We ask the question, What are the dental manpower requirements of the 1969 Illinois population as a function of the level of service expressed in terms of average visits per person per year?

Effect of Population and Dentist Productivity

In order to address the subject of dental manpower requirements, it is necessary to characterize in some way an adequate, or desirable, quantity of dentists for a given population. Since an individual's requirement for dental care is usually expressed in terms of the number of dental visits per year, it seems reasonable that this same measure could be employed for a particular population, recognizing that the needs of the population are simply the sum of the needs of its members. It then follows that the visits provided by all the dentists equal the visits consumed by all the patients, with any one dentist providing some fraction of the total.

If we combine these two notions we find that we can derive an expression that, for a given productivity, expresses a manpower requirement in terms of either average visits per person per year or the dentist-to-population ratio. Using the national average of 3629 visits per year per dentist* as the given productivity, this relationship can be expressed symbolically as follows:

**The 1968 Survey of Dental Practice*, op. cit.

$$\frac{D}{N} = \frac{V/N}{3629}$$

where D/N = the dentist-to-population ratio,

V/N = the number of visits per person per year,

Setting V/N equal to 2 gives a value to D/N of 55 per 100,000. The 1969 Illinois statewide average of 41.4 FTE dentists per hundred thousand gives an average annual visits per person of about 1.5.*

Effect of Distribution and Mobility

The expression derived for the relationship between dentists and population can be used to express dentist requirements in the aggregate, but it ignores the effect of geographic distribution of both the population and dental manpower. It is, of course, possible for a region to have an adequate dentist-to-population ratio while certain subregions may be severely lacking in manpower. What is relevant in terms of the provision of dental care is not this total ratio, but the ratio in a region within which an individual can seek care. Such a region might be called a "service region." The size of a service region should depend on what we consider a reasonable distance to travel for dental care. One study has shown that approximately 90 percent of the dental patients sampled did not leave their own county for dental care.† On the other hand, it does seem reasonable that patients could travel 30 miles or so to obtain routine dental examinations. In the case of Illinois, this type of patient mobility would often lead to travel across county lines, but would rarely lead to travel into other than adjacent counties.

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*The 1969 Illinois population estimates have been taken from *Sales Management: The Marketing Magazine*, Vol. 104, No. 13, June 1970, pp. D-43 to D-52.

†American Dental Association, Bureau of Economic Research and Statistics, "Survey of Patient-to-Dentist Travel," *Journal of the American Dental Association*, Vol. 53, October 1956, pp. 461-466.

As a result, two variants of patient mobility have been used in examining the distribution of dental manpower. In the first case, it is assumed that patients do not travel outside their own county for care, leading to a set of service regions coincident with the 102 counties of the state. In the second case, it is assumed that a patient can and will travel to adjacent counties. It seems reasonable to assume that the actual extent of patient mobility is somewhere between these two extremes.

Consider, first, the case in which each patient's mobility is restricted to his county (Case 1). In this case, the availability of dentists within the service area defined by a particular county is reflected by the dentist-to-population ratio of that county. Thus, for any selected ratio, it is possible to calculate the dentists required for a given county by simply taking the product of the ratio and population. The deficit or surplus of dentists is then apparent. Given our assumptions concerning patient mobility, a surplus of dentists in one county is of no value in relieving a shortage in another. Thus, for any given ratio, the additional number of dentists needed (if any) is equal to the sum of the deficits in each of the 102 counties. A deficit of dentists calculated in this fashion will be considered to be an upper bound on the additional number actually needed, since the procedure explicitly prohibits a potential mobility across county lines.

In the second case (Case 2), it is assumed that patients may travel to adjacent counties to obtain dental care. In order to calculate dentist requirements in this case, it is necessary to make an additional assumption about the way in which patients travel across county boundaries to obtain care. For this case, it is assumed that patients travel in such a way that total utilization of the dentist population is maximized within the constraints of patient mobility. A manpower deficit based on these assumptions is conservative, and the resulting calculation of dentists needed to meet any given service level for this case is viewed as a lower bound on the number needed. Thus, the two cases serve to delineate upper and lower bounds and to illustrate the significance of patient mobility in determining manpower requirements.

To calculate dentist requirements in Case 2, for a given ratio, the surplus or deficit of dentists in each county is first computed as was done for Case 1. Since travel across county lines is allowed, it is now possible for patients in a county with a deficit to travel to an adjacent county that has a surplus in order to obtain dental care. In this way, a county with a deficit can, in effect, borrow dentists from a county with a surplus.*

Figure 1 shows calculated total dentist deficit for both cases as a function of the average visits per person per year and the equivalent ratio of dentists to 100,000 people. It appears that differences in patient mobility as reflected in Cases 1 and 2 can lead to differences in the total deficit of as much as 80 dentists. Thus, for an average 1.1 visits, there is a total deficit of 60 (Case 2) or 140 dentists (Case 1). As the desired visits per person are increased, the number of counties with a surplus is decreased. At approximately two visits per person per year there are no counties with a surplus and, thus, the total deficit is the same for both cases.

If we take as a standard the 1968 national average of 1.3 visits per person per year, Fig. 1 reveals that there is, as of 1969, a shortage of from 220 to 280 FTE dentists in the State of Illinois.** A more pessimistic picture is revealed if we assume that the national average of 1.3 visits per year is held down by the inability of many to pay for dental services, and the "unconstrained" demand for services is reflected by the national average of 2.3 visits per year for those families who had annual incomes over $7000.† Under the latter assumption, there would be a shortage of some 2400 dentists. It is important to recognize that such a shortage is not real in the sense of a present demand for services at that level, although there may be a need from a professional

*For an example and further discussion of the problem of optimum allocation see Appendix B.

***Current Estimates from the Health Interview Survey United States-1968*, U.S. Department of Health, Education and Welfare, National Center for Health Statistics, Washington, D.C., June 1970.

†*Dental Visits United States, July 1963-June 1964*, U.S. Department of Health, Education and Welfare, National Center for Health Statistics, Washington, D.C., October 1965.

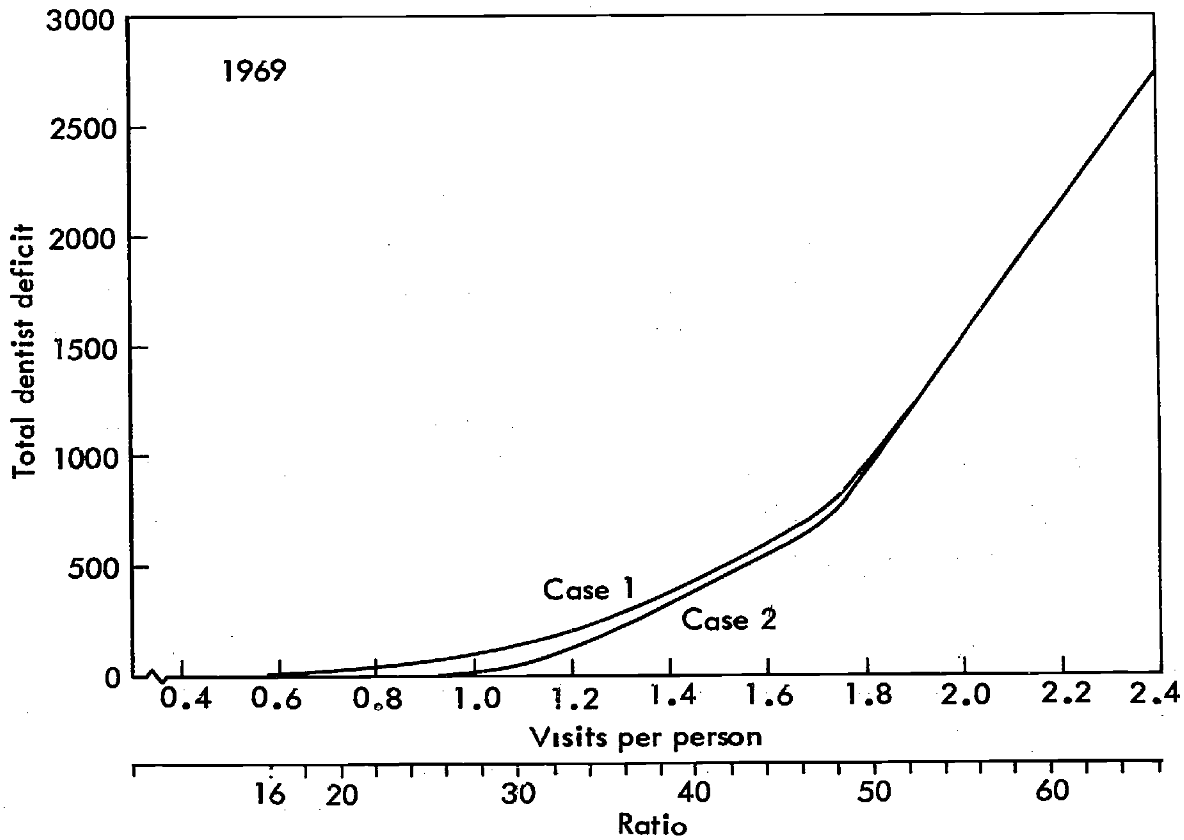

Fig. 1--Dentist deficit as a function of average visits per person per year and ratio per 100,000 population, Case 1 and Case 2

point of view. If, however, economic and social constraints were to be removed from the low income segment of the population, e.g., through national health insurance, such a shortage could become a reality.

III. REGIONAL ANALYSIS OF 1969 DENTAL MANPOWER

Manpower requirements in Fig. 1 in the preceeding section were calculated on the assumption that additional dentists would distribute themselves optimally, i.e., as required in the deficit areas.

There is, however, a far greater total requirement if it is assumed that additional dentists will distribute themselves in the same manner as the existing manpower pool. This follows from the fact that those areas with greater deficits generally have a small proportion of practicing dentists. Figure 2 shows the number of additional dentists needed to fill the total deficit given that these additional dentists follow the 1969 geographic distribution. For comparison, the number required to maintain the 1969 state average of 1.5 visits per person per year is

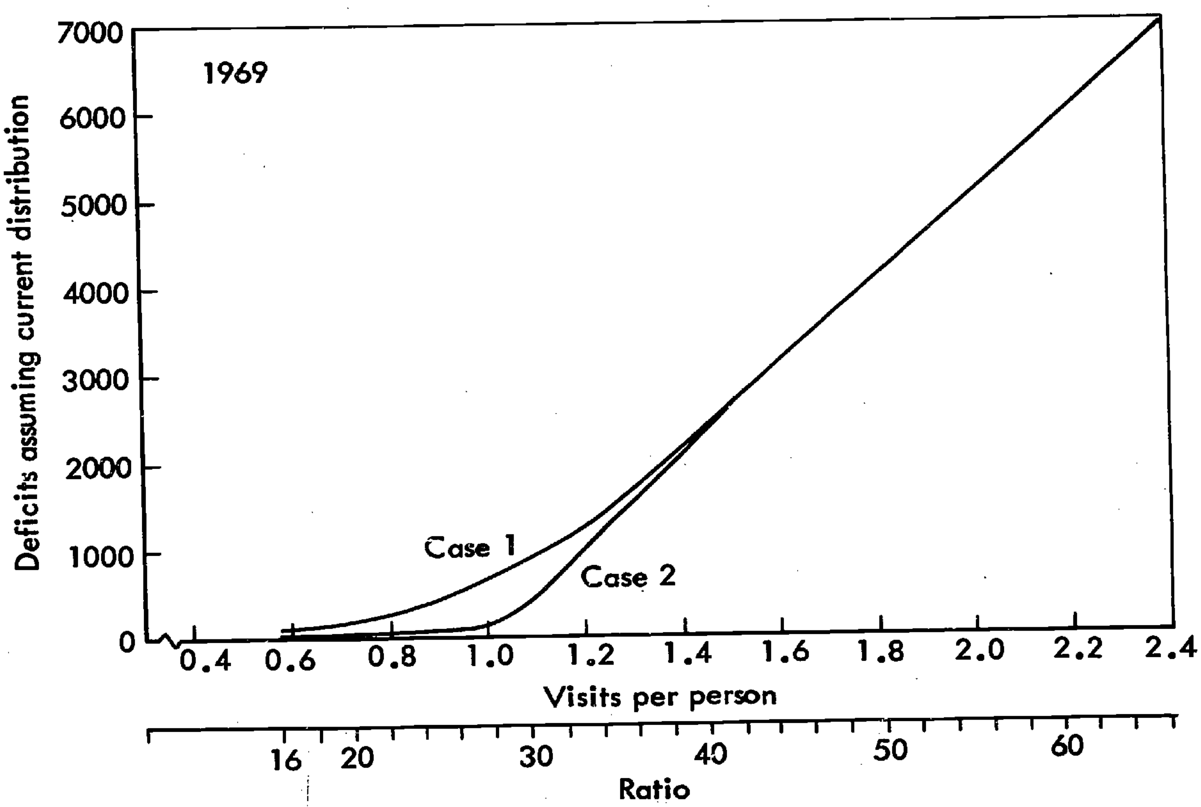

Fig. 2--Projected dentist deficit if geographic distribution follows the 1969 pattern

approximately 2600 (Cases 1 and 2), although Fig. 1 reveals that there are actually from 440 to 480 "vacancies." Thus, there are two aspects to dental manpower distribution in Illinois: one of uneven distribution, and the other the coincidence of areas with a deficit and a small proportion of the dental manpower pool. The fact that the deficit of Fig. 2 is so much higher than that of Fig. 1 suggests that simply increasing the supply of Illinois dentists without altering the distribution is not an efficient means to insure minimum levels of available dental care.

To further examine the effect of dentist distribution, the state has been divided into the seven regions shown in Fig. 3. These regions were derived with the following two considerations in mind:

1. The counties of a region should be contiguous.
2. The counties of a region should be similar in terms of the availability of dental care.

To obtain the regions, the dentist-to-100,000 population ratio for each county was computed by calculating the total number of dentists in a county and its adjoining counties and then dividing this total by the corresponding population. Counties were assigned to one of the following three groups according to their ratios of FTE dentists to 100,000 population:

1. 9-30 dentists per 100,000 population.
2. 30-35 dentists per 100,000 population.
3. 35-48 dentists per 100,000 population.

With minor modifications, adjacent counties in similar groups were joined to produce the seven regions of Fig. 3.

Table 2 shows the population and dentist-to-100,000 population ratio for each of the seven regions. It will be noticed that Region 1 (including Cook County) has the highest ratio (47.56), while the region with the second highest ratio has only 36.36 dentists per 100,000 population. It appears that uneven distribution of dentists in Illinois can be characterized by a relatively high number of dentists in relation to the population for the Cook County area with the remaining regions clustering around a ratio of about 30 dentists per 100,000 population.

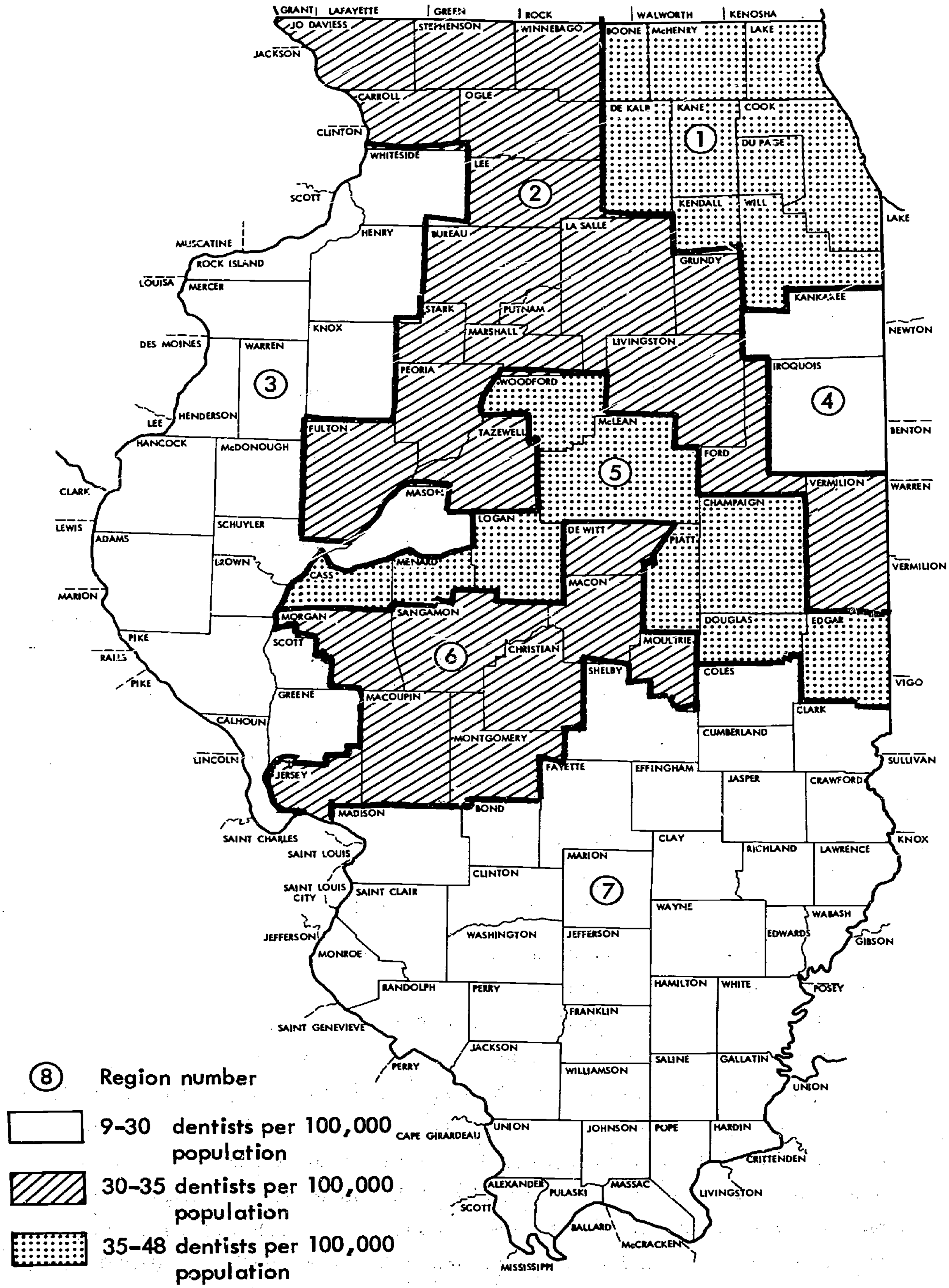

Fig. 3--Distribution of FTE Illinois dentists by dentists per 100,000 population groups, 1969

Table 2

STATUS OF ILLINOIS DENTIST SUPPLY IN 1969

Region	*FTE Dentists*	*Population*	*FTE Dentists per 100,000*
1	3,371.64	7,089.9	47.56
2	377.33	1,148.4	32.86
3	167.57	598.2	28.01
4	36.28	137.8	26.33
5	141.41	388.9	36.36
6	158.42	485.5	32.63
7	333.61	1.235.6	27.00
State	4,586.26	11,084.3	41.38

Figure 4 gives the total dentist deficit for each of the seven regions. Region 1 shows no deficit (Case 2) based on the state average of 1.5 visits per year, while each of the other regions has a deficit. Thus, the surplus of Region 1 is sufficient (if redistributed) to eliminate the deficits of the remaining six regions.*

It is natural to inquire into the significance of the dental deficits that have been calculated. What do they mean in terms of the state's dental health, and what is their magnitude in terms of the provision of services? The answer to the former question is beyond the scope of this study; however, there are some measures of the quantitative significance of deficits. One such measure is the percentage of the state's total dental visits that is not provided at a particular service level due to the total dentist deficit. Figure 5 shows this percentage for various service levels expressed in terms of average visits per year. Thus, at the national average of 1.3, 5.5 to 7 percent of the total visits that should be delivered are not. Similarly, at the state average of 1.5, 9.5 to 10.5 percent are unavailable due to the uneven distribution of dentists.

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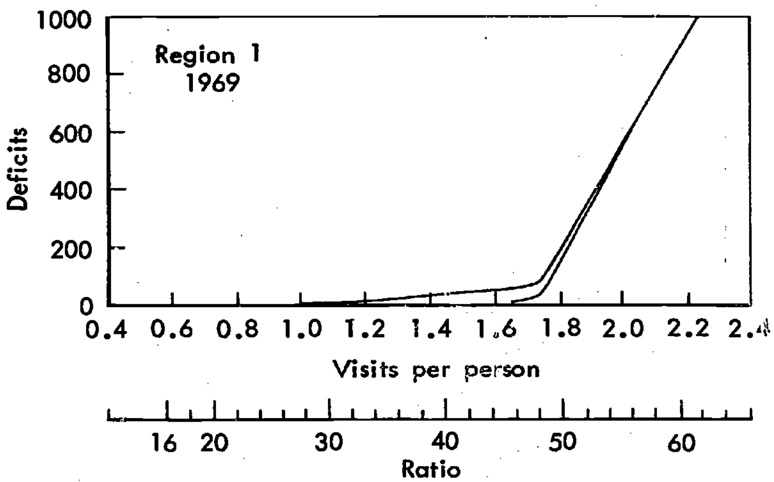
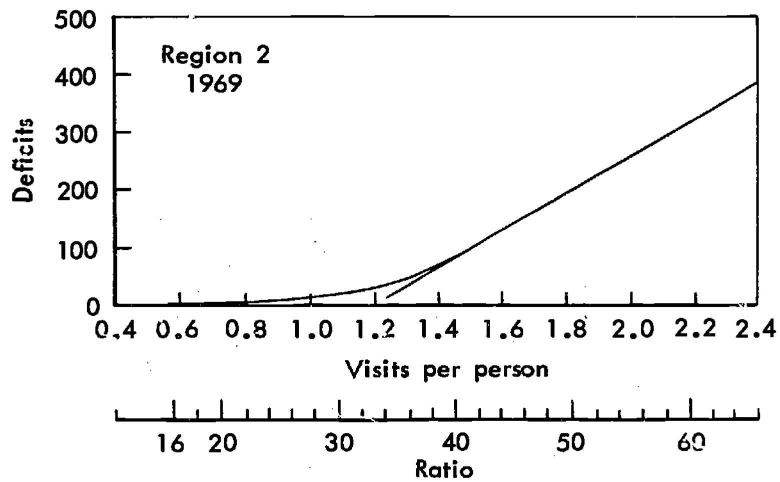
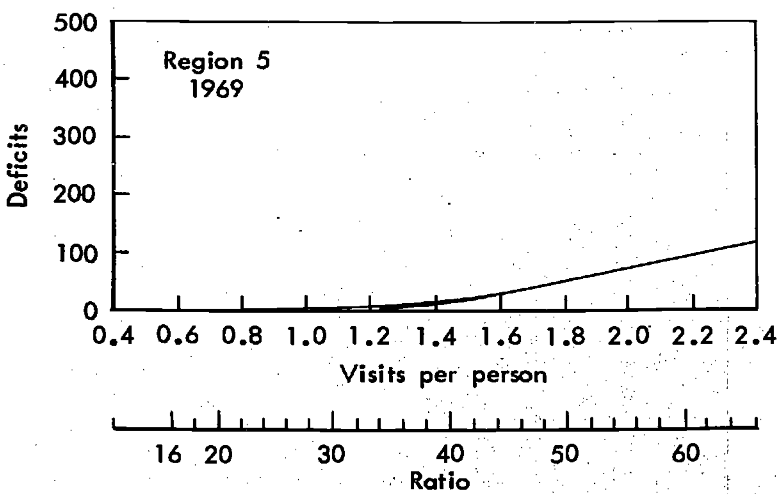
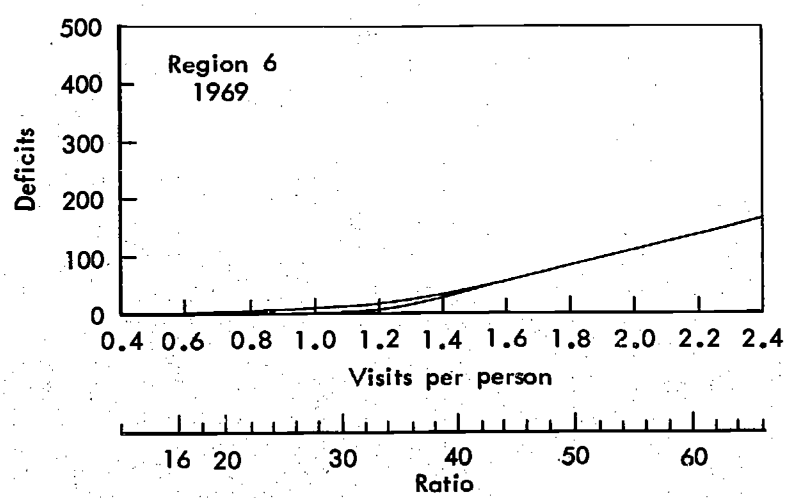
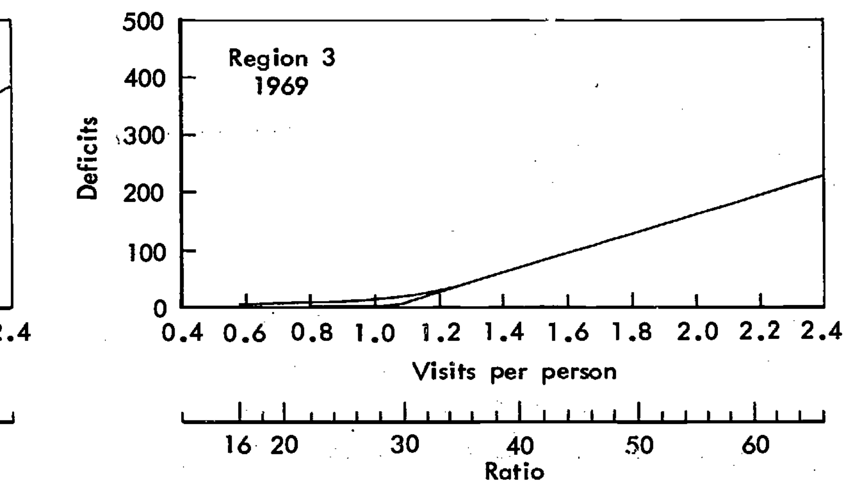
*For the statewide average visits per person per year, the sum of the surpluses equals the sum of the deficits.

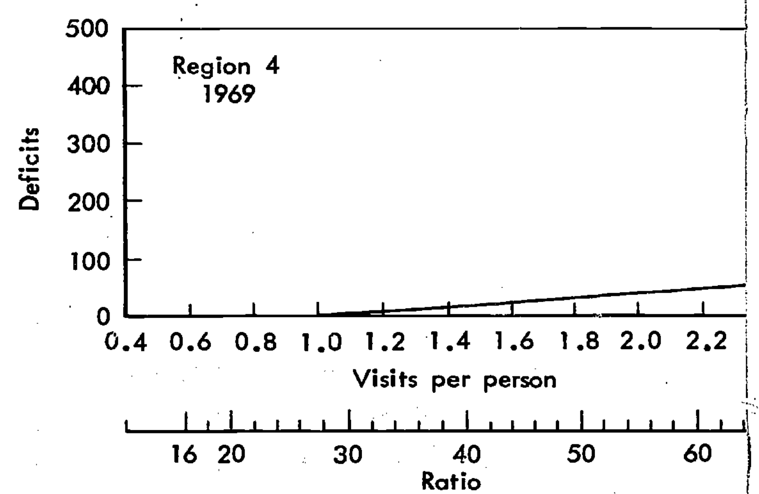

Region 1
1969
Deficits
1000
800
600
400
200
0
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
16 20 30 40 50 60
Ratio


Region 2
1969
Deficits
500
400
300
200
100
0
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
16 20 30 40 50 60
Ratio


Region 5
1969
Deficits
500
400
300
200
100
0
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
16 20 30 40 50 60
Ratio


Region 6
1969
Deficits
500
400
300
200
100
0
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
16 20 30 40 50 60
Ratio





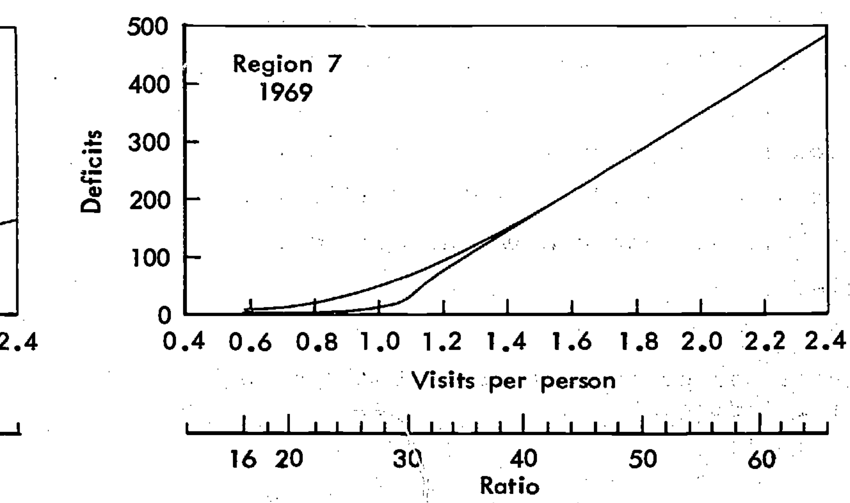


Fig. 4--Total 1969 Illinois dentist deficit by region, Case 1 and Case 2

Note: Deficit scale in Region 1 is double that in all others.

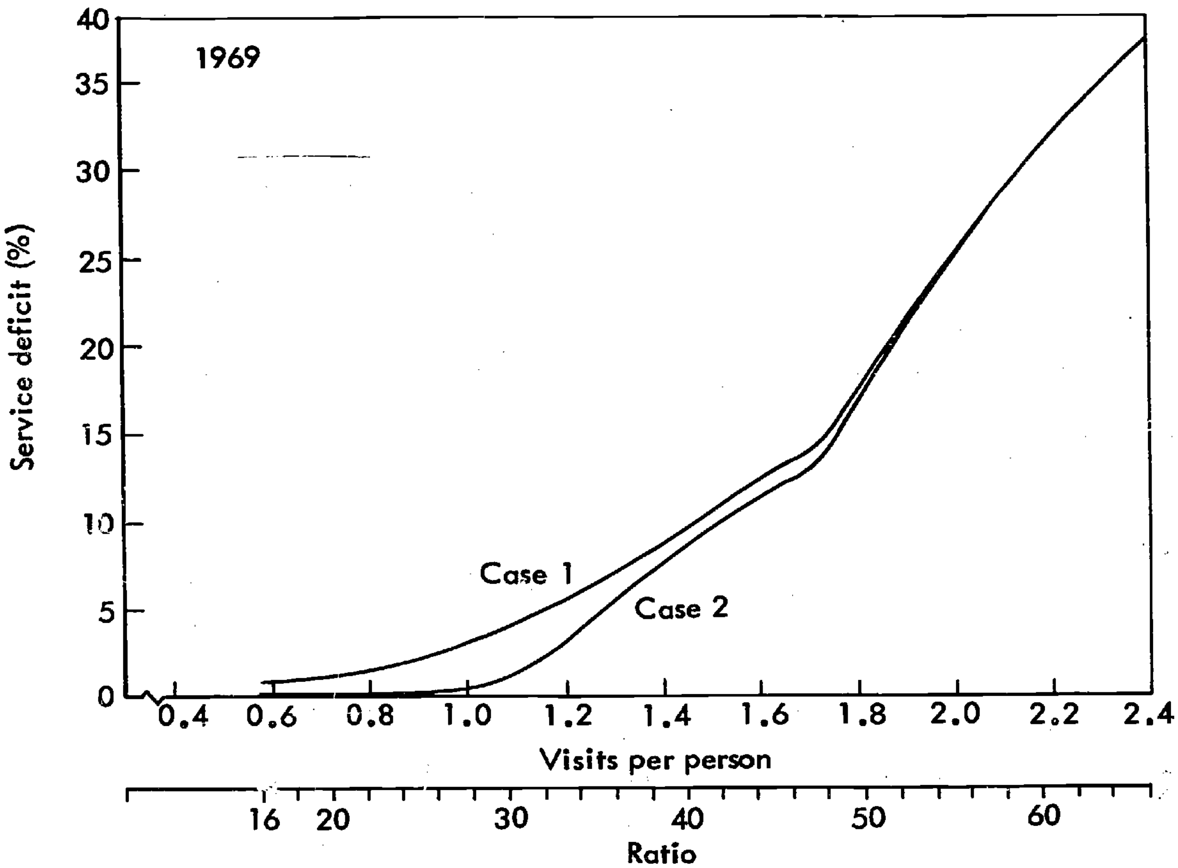


Fig. 5--Dental visits not provided due to dental manpower deficit, Case 1 and Case 2

IV. IMPACTS OF CHANGES IN PRODUCTIVITY

Besides altering the distribution of dentists, deficits can be relieved by increasing dentist productivity. In the previous calculation of deficits, an FTE dentist was defined as providing 3629 visits per year. Changes in this number will, of course, change the total deficit. Figure 6 shows the dentist deficit as a function of productivity defined in terms of the visits handled per year divided by the national average of 3629. Each curve of Fig. 6 corresponds to a particular level of care

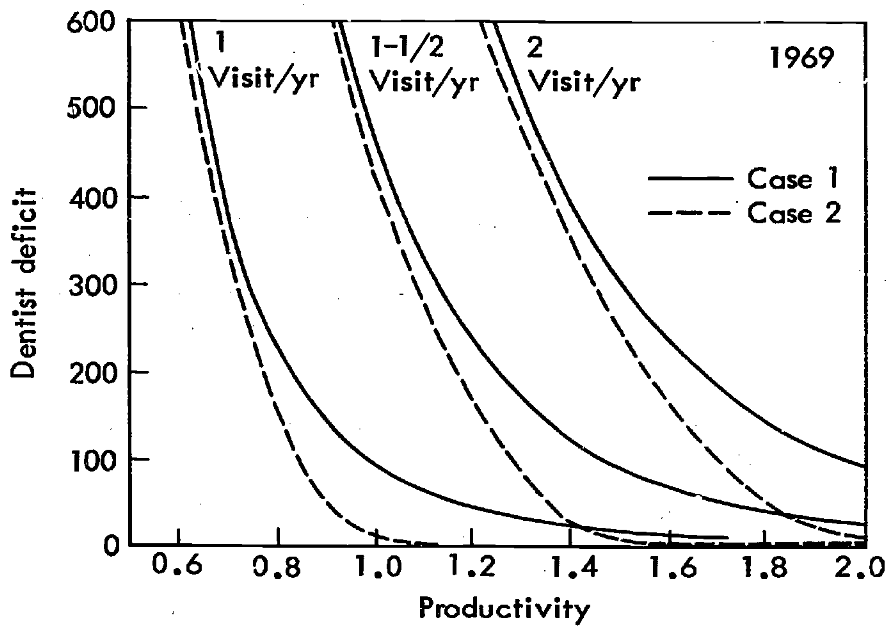


Fig. 6--Effect of productivity changes on dental manpower requirements

(visits per person per year). The steep slope of these curves indicates the effect that small changes in productivity can have. For example, at a level of 1.5 visits, it is seen that a 10 percent increase in productivity (1.1 × 3629) reduces the deficit by approximately 150 dentists. We shall return to the subject of dentist productivity in the final section.

V. FORECASTING DENTIST SUPPLY

The preceding sections have dealt with the problem of assessing the current status of the availability of dentists in Illinois. The analysis also shows the number of dentists needed to meet selected standards measured in terms of ratios and visit-per-person availability. We now turn to the problem of estimating the future total supply of dentists in Illinois, using the current manpower pool of dentists as a point of departure. The major purpose is to relate future supply to planned educational output in a way that both allows for the other major factors affecting supply and permits the exploration of various alternatives.

SUPPLY EQUATION

The approach to supply forecasting used in this study is fundamental in the sense that the method employed models the processes that govern temporal changes in the manpower pool. This is in contrast to techniques that simply model trends or changes in the manpower pool by extrapolation. The methodology relies both on analysis of the processes that underlie change and on the estimation of parameters and variables that govern the rates of change in those processes.

More specifically, the methodology is designed to allow explicitly for the effects through time of rates of graduation, migration, retirement, and death.* To do this, it is necessary to begin with the age distribution and number of dentists in the state for the current year. The analysis then starts by examining what changes will occur in the passing of 1 year, 2 years, and so on through the forecasting period.

The most obvious effect of the passing of a year's time is that each member of the manpower pool will be one year older, if alive, and thus change the age distribution. How will dentists leave the manpower pool? Some will die, some will retire, and some will simply not practice in the state any more for various reasons. We shall call this

*Productivity and distribution became important factors only when an attempt is made to analyze the service implications of the total manpower pool.

latter effect outmigration. How will dentists enter the pool? Most entrants will be recent dental school graduates taking up practice in Illinois, but not necessarily graduates of that year. Some may delay their practice for different reasons, including military service. At any rate, there will be a quantity of recent graduates taking up practice for the first time. The remaining new entrants we shall attribute to the effect of what we call inmigration. Combining all of these factors, we derive a supply equation that has as parameters the probability of death, the probability of retirement, and migration expressed as the net fraction of graduates from a particular institution who were a given age at graduation and who take up practice in Illinois some years after graduation. The equation is completely general in the sense that for any realizable set of dentist populations and graduates there exist values of the parameters such that the equation holds.*

THE STUDENT FLOW MODEL

This approach to forecasting supply can be related directly to policy decisions of educational planners by relating the number of future graduates to the planned levels of enrollment. This can be done by means of what is generally called a "student flow model." Using the student flow model and the supply equation, it is possible to examine the impact of education on supply for various estimates of:

- Death rates.
- Retirement rates.
- Migration rates.

Student flow models describe the progress of students through an educational system by mathematically representing the structural components of the system and the relationships between these components. The structural components are viewed generally as a series of "states" or levels through which students pass, and the relationships between the states are referred to as "paths." Appendix A provides a full discussion.

*For a detailed discussion of this equation see Appendix B.

ESTIMATING PARAMETERS

The supply forecasting methodology uses the current manpower pool, together with data on its age distribution, and current enrollment as a point of departure. Enrollment is used to estimate graduates who are then added to the pool allowing for migration of Illinois students out of the state and non-Illinois students into the state. The parameters of the student flow model are the retention rates in each of the schools in Illinois. The parameters of the supply equation are death rates, retirement rates, and migration rates. Each of these sets of parameters is discussed below. Since the emphasis of this study is on basic methodology, only a minimal amount of effort was expended on parameter estimation. The model can be used to estimate the quantitative importance of each of the parameters and in that way provide guidance for future research on the factors affecting these parameters.

Retention Rates

Retention rates for the student flow model are estimated from historical data as described in Appendix A. Table 3 shows past undergraduate enrollment for Illinois schools and the total United States. Undergraduate refers to students enrolled in programs leading to a D.D.S. or D.M.D. degree.

The calculated retention rates between each of the levels for each of the schools, the state total, and the total United States, together with the 95 percent confidence intervals, are shown in Table 4.

By the assumptions outlined in Appendix A, these retention rates are random variables with approximate normal distributions. The confidence intervals give some indication of the reliability of the estimates. For example, using Loyola, the retention rate between level 1 and level 2 is .968. The 95 percent confidence interval is ±.016. The interpretation to be given to the confidence interval is that for repeated calculations, the true value of the retention rate will fall in the interval from .952 to .984 95 percent of the time.

Table 4

RETENTION RATES BETWEEN LEVELS AND 95 PERCENT CONFIDENCE INTERVALS

Item	*Levels 1-2*	*Levels 2-3*	*Levels 3-4*	*Levels 4-Graduate*
Loyola	.968 ± .016	.983 ± .012	.965 ± .018	1.000 ± 0
Northwestern	.887 ± .030	.983 ± .014	.967 ± .019	.991 ± .011
University of Illinois	.947 ± .020	.984 ± .012	.971 ± .016	.993 ± .009
State of Illinois	.936 ± .013	.983 ± .013	.968 ± .010	.995 ± .004
Total United States	.951 ± .003	.977 ± .002	.987 ± .001	.995 ± .001

Death Rates and Retirement Rates

The death rates for dentists used in the supply equation were based on mortality statistics for the white male population.* The retirement rates were computed from the statistics on the anticipated retirement of dentists in the 50 to 59 age bracket as surveyed in *The 1968 Survey of Dental Practice*.† The results are shown in Table 5.

Table 5

ANNUAL DEATH AND RETIREMENT RATES

Dentist Age	*Death Rate*	*Retirement Rate*
22-24	.0019	0
25-29	.0016	0
30-34	.0018	0
35-39	.0026	0
40-44	.0041	0
45-49	.0068	0
50-54	.0112	.0024
55-59	.0179	.0082
60-64	.0271	.0690
65-69	.0394	.2330
70-74	.0595	.2830

*These rates were provided through the courtesy of James N. Ake, Chief, Data Services Section, Division of Dental Health, Bureau of Health Manpower Education, National Institutes of Health, Bethesda, Maryland.

†Op. cit.

Migration Rates

To facilitate the analysis, it was assumed that migration rates are a function only of years since graduation and not age-dependent. The migration rates were calculated separately for each dental education institution in Illinois and all non-Illinois institutions were grouped into a category "other U.S. dental institutions." The dental education institutions are listed as follows:

1. University of Illinois.
2. Northwestern.
3. Loyola.
4. Southern Illinois University.
5. Other U.S. dental institutions.

The fifth "institution" (other U.S. dental institutions) combines the effects of all non-Illinois schools. To determine the migration rates associated with each institution, the percent of the graduating class practicing in Illinois (excluding dentists in activities not related to patient care) as of November 1969 was computed for each class from each institution from 1947 through 1969. These computations were performed using the 1969 ADA membership records and data on graduating class sizes for these years. The results are displayed in Figs. 7 and 8.

Figure 7 displays some interesting comparisons of institutions with respect to dentist migration patterns. Approximately 66 percent of University of Illinois graduates stay in the state, while only 20 percent of those who graduate from Northwestern stay. This difference is due, most likely, to differences in the composition of the student bodies, e.g., state of residence, but for the purposes of this initial study the difference will be viewed as an institutional effect.

Migration rates for each of the institutions were derived from this data using the smoothed curves (dashed lines) on Figs. 7 and 8.* As an

*Because of a change in the institution, migration rates for Loyola are based on data since 1953. Migration rates of the planned Southern Illinois University are assumed to be the same as those of the University of Illinois.

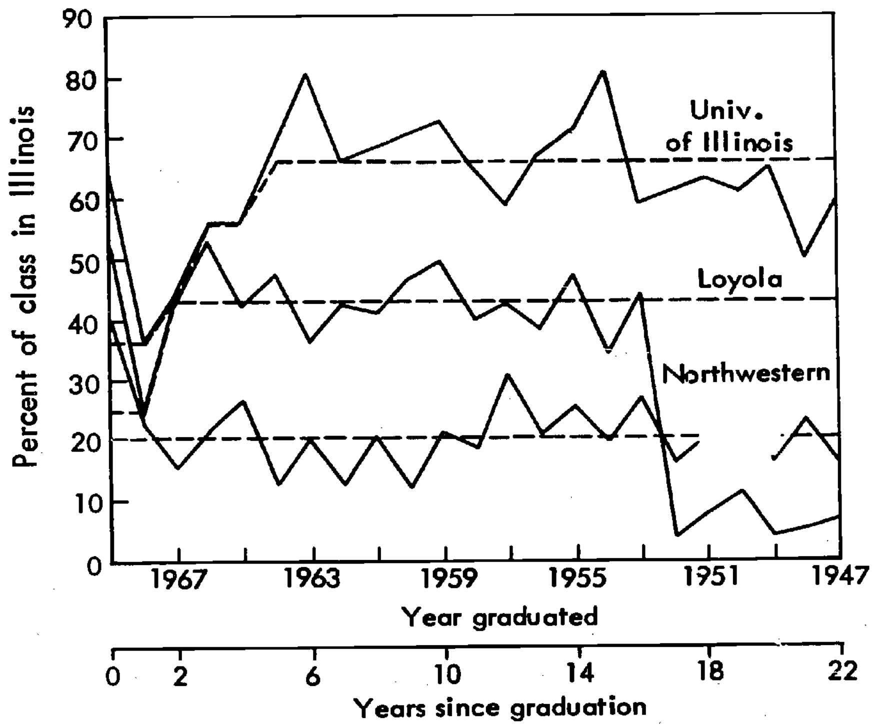


Fig. 7--Graduates of Illinois dental schools practicing in Illinois

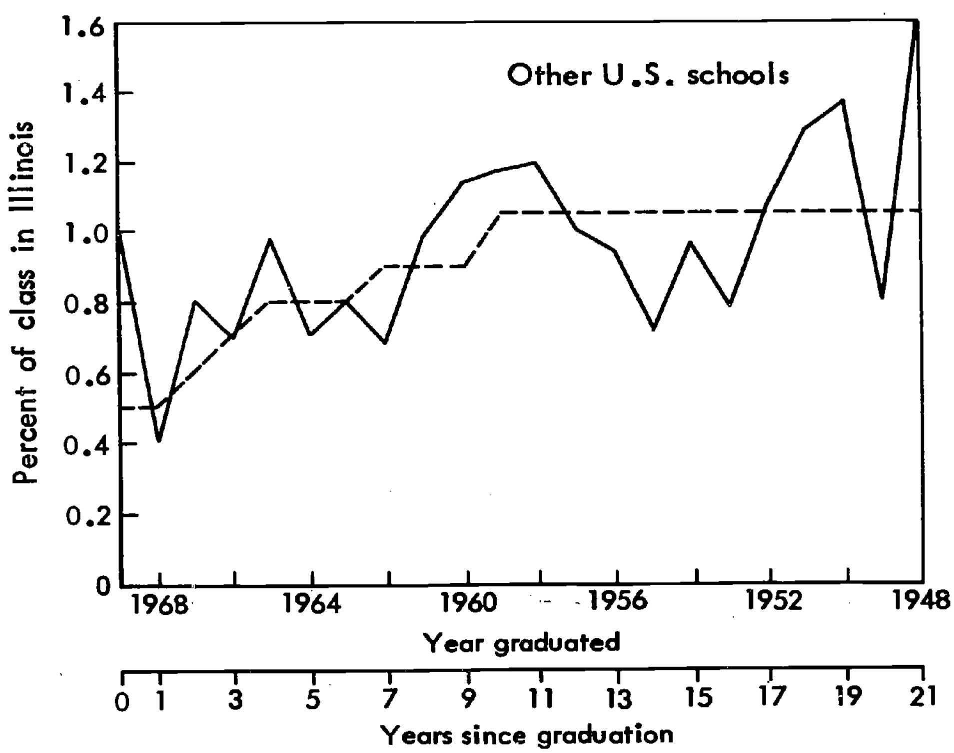


Fig. 8--Graduates of non-Illinois dental schools practicing in Illinois

example, consider the computation of the percent of Loyola graduates that take up practice in Illinois 2 years after graduation. Fig. 7 indicates that for the class of 1968, 25 percent were practicing in Illinois in 1969, while 43 percent from the class of 1967 were practicing. Thus, there was a net increase of 18 percent (43 percent minus 25 percent) from one year after graduation to two years after graduation. This computation, of course, ignores the fact that effects other than migration, i.e., death and retirement, also influence the distribution shown in these figures. However, the dentists used in these computations are sufficiently young so that the effect of death and retirement should be minor. All the smoothed curves of Figs. 7 and 8 are monotonically increasing.

Thus, it appears that for the classes since 1955 no marked outmigration has occurred. This is taken as evidence that there is no significant net outmigration of dentists after they once settle in Illinois, and no allowance is made in the projection for outmigration of dentists who have taken up practice in the state.

VI. FUTURE ILLINOIS DENTAL MANPOWER SUPPLY

In this section the supply equation and student flow model are used to estimate future Illinois dental manpower supply. The importance of these projections is not the specific numbers generated but the fact that a direct link is provided between educational plans and supply and a means is provided for examining the impacts of changes in the parameter estimates and educational plans. Using the parameters described in the preceeding section, the models require as inputs the current manpower supply and its age distribution and the number of planned graduates and their age distribution.

THE CURRENT SUPPLY

The current pool of FTE dentists was described in the first section. The total number was 4586. A summary tabulation of the age distribution of this group in five-year intervals is shown in Table 6.

Table 6

AGE DISTRIBUTION OF ESTIMATED FTE DENTISTS

Age Group	*Percent*
Under 25	0.18
25 - 29	7.60
30 - 34	12.37
35 - 39	15.40
40 - 44	13.31
45 - 49	16.39
50 - 54	12.78
55 - 59	11.11
60 - 64	8.70
65 - 69	1.93
70 and over	0.23

DENTAL EDUCATION IN ILLINOIS

Estimates of future graduates for the supply projections are derived through the student flow model from current and planned enrollment. Increased enrollment is one of the primary goals of the HEC, and, partly as a result of its efforts, Illinois schools are planning a significant increase both in total enrollment and in the number of Illinois residents enrolled. It is hoped that increasing the number of Illinois residents trained will increase the number of newly trained dentists remaining in the state. The following is a brief description of enrollment patterns in dental education in the state.

Dental education in Illinois is currently provided by three schools, with a fourth planned to start operation shortly. In the 6-year period from 1965 to 1970, these schools produced 1370 graduates or about 6.7 percent of the dentists trained in the U.S. during this period. The average annual graduation rate for the state during this period was 227. Of this figure, Loyola and the University of Illinois have each contributed 36 percent and Northwestern 28 percent.*

The projected new registrations submitted to the HEC by each of the schools, including those for the new dental education program at Southern Illinois University, are shown in Table 7.

Table 7

PROJECTED NEW REGISTRATIONS

Year	*Loyola*	*Northwestern*	*Southern Illinois University*[a]	*University of Illinois*	*State Total*
1970-71	128	92	--	99	319
1971-72	128	92	24	130	374
1972-73	128	92	24	165	409
1973-74	128	92	24	165	409
1974-75	128	92	24	165	409
1975-76	128	92	24	165	409

[a]Southern Illinois University plans to expand to 48 new registrants in 1976-77.

These projections show an average first year class size of 388 for the state as a whole during the 6-year period, 1970-71 to 1975-76. The similar figure for the preceding 6 years, 1964-65 to 1969-70, is 289.

*These figures are based on the data shown in Table 3.

This represents a 35 percent increase in enrollment. Each school's contribution to this increase, on a percentage basis, is as follows:

	Contribution (%)
Loyola	22.6
Northwestern	4.6
Southern Illinois University	20.1
University of Illinois	52.7

Currently, of the total of 6676 dentists in Illinois, 1512 graduated from a non-Illinois dental school.

For the 15-year period from 1954 to 1969, the average proportion of University of Illinois Dental School graduates remaining in Illinois has been 66 percent. The average proportion from the Loyola and Northwestern University dental schools for this same period has been 43 and 20 percent, respectively. In 1968-69, the percentage of total enrollees at the University of Illinois who were Illinois residents was over 95 percent, while the average percentage for Loyola and Northwestern was about 40 percent.

Loyola and Northwestern currently are planning to increase the number of Illinois residents admitted to their dental schools. The resident/nonresident split in enrollment for these two schools during academic year 1967-68 is shown in Table 8.

Table 8

RESIDENT/NONRESIDENT ENROLLMENT
COMPARISON, LOYOLA AND NORTHWESTERN
1967-1968

Enrollment Type	*Number*	*Percentage*
Loyola		
Resident	186	51.5
Nonresident	175	48.5
Total	361	100.0
Northwestern		
Resident	73	24.4
Nonresident	226	75.6
Total	299	100.0

The past enrollment data show a resident/nonresident split of about 50-50 for Loyola and 25-75 for Northwestern. The average number of new registrants planned for the 10-year period, 1970-71 to 1979-80, shows a shift in the resident/nonresident split.

By applying the calculated retention rates and the student flow model and assuming that the probability of success for the non-Illinois resident is equal to that for the Illinois resident, the estimated average resident/nonresident split in total enrollment for the 10-year period, 1970-71 to 1979-80, is shown in Table 9. These figures show an Illinois resident increase of from 50 to 60 percent for Loyola and from 25 to 30 percent for Northwestern.

Table 9

ESTIMATED AVERAGE TOTAL ENROLLMENT
1970-71 to 1979-80

	Number	*Percentage*
Loyola		
Resident	296	60.4
Nonresident	194	39.6
Total	490	100.0
Northwestern		
Resident	102	30.0
Nonresident	238	70.0
Total	340	100.0

IMPACT OF INCREASED REGISTRATION ON TOTAL ENROLLMENT AND GRADUATES

Given the expected number of new registrations and the calculated retention rates, the student flow model is used to estimate the total enrollment and the number of graduates for each of the schools during the period 1970-1980. These estimates are shown in Table 10.

From Table 10 it can be seen that, based on current plans and past attrition history, it is estimated that during the period shown Illinois dental schools will provide 14,716 student years of undergraduate dental education and confer 3297 degrees. This is an average of 330 new dentists per year over the 10-year period compared with an average of 227 for the preceding 6 years. This represents a 45 percent increase in output.

Table 10

ESTIMATED TOTAL ENROLLMENT AND NUMBERS OF GRADUATES[a]

Year	*Loyola* Total Enroll-ment	*Loyola* Grad-uates	*Northwestern* Total Enroll-ment	*Northwestern* Grad-uates	*Southern Illinois*[b] Total Enroll-ment	*Southern Illinois*[b] Grad-uates	*University of Illinois* Total Enroll-ment	*University of Illinois* Grad-uates	*State Total* Total Enroll-ment	*State Total* Grad-uates
1970-71	473	102	337	67	--	--	377	89	1187	258
71-72	488	113	348	84	24	--	407	90	1267	287
72-73	492	117	341	80	47	--	469	88	1349	285
73-74	492	117	339	78	69	--	531	88	1431	283
74-75	492	117	339	78	91	22	592	116	1514	333
75-76	492	117	339	78	91	22	625	149	1547	366
76-77	492	117	339	78	115	22	625	149	1571	366
77-78	492	117	339	78	138	22	625	149	1594	366
78-79	492	117	339	78	161	22	625	149	1617	366
79-80	492	117	339	78	183	43	625	149	1639	387
Total	4897	1151	3399	777	919	153	5501	1216	14716	3297
Average	490	115	340	78	92	15	550	122	1472	330

[a] Assumes 1975-76 new registrant rates carry forward to 1979-80 except Southern Illinois University.

[b] Assumes total United States transition probabilities and that the new registrant rate increases to 48 in 1976-77.

IMPACT OF INCREASED REGISTRATION ON FUTURE SUPPLY

The methodology described in this report provides a direct link between future supply and educational plans, with explicit allowance for the impacts of other major factors. This allows the quantitative assessment of many alternative policies. To illustrate this, projections based on our estimated parameters and current enrollment plans will be compared to the alternative of no increase in enrollment. The first case will be referred to as the base-line projection. In a later section, we will examine the implications of altering the migration parameters.

Using the student flow model and registration data supplied by the schools through the HEC, graduation projections to the year 2000 are shown in Table 11. It is recognized that the schools will undoubtedly continue to increase enrollment over the entire period; however, no data are available for the out years, and our primary concern is with the more immediate years. As a result, constant levels have been carried out beyond the years for which data exist.

Graduation projections for all other U.S. schools are estimates provided by the Division of Dental Health, Public Health Service.* In the absence of historical data for Southern Illinois University, its retention rates were assumed equal to those for the U.S. as a whole.

The age distribution of graduates was taken to be the 1970 national average as indicated from data in the ADA tapes and is assumed to remain constant over time; a summary tabulation by age group is shown in the following:

	Percentage
Under 25	10.6
25 - 29	81.2
30 - 34	6.6
over 35	1.6

Figure 9 shows total expected supply of practicing dentists in Illinois and indicates the portion attributable to graduates after 1970.

*These estimates, based on projected dental school expansion and construction, were made by James N. Ake, Chief, Data Services Section, Division of Dental Health, National Institutes of Health.

Table 11

GRADUATES AND PROJECTED GRADUATES

Year	University of Illinois	Northwestern University	Loyola University	Southern Illinois University	Illinois Total	Other U.S. Schools	Total
1960	81	90	79	0	250	3003	3253
1961	72	83	85	0	240	3050	3290
1962	76	79	94	0	249	2958	3207
1963	77	64	94	0	235	2998	3233
1964	83	64	87	0	234	2979	3213
1965	77	56	95	0	228	2953	3181
1966	75	55	72	0	202	2996	3198
1967	65	65	91	0	221	3139	3360
1968	93	71	77	0	241	3216	3457
1969	81	68	87	0	236	3197	3433
1970	88	66	78	0	232	3463	3695
1971	89	67	102	0	258	3523	3781
1972	90	84	113	0	287	3501	3788
1973	88	80	117	0	285	3634	3919
1974	88	78	117	0	283	3803	4086
1975	116	78	117	22	333	3949	4282
1976	149	78	117	22	366	4091	4457
1977	149	78	117	22	366	4218	4584
1978	149	78	117	22	366	4257	4623
1979	149	78	117	22	366	4315	4681
1980	149	78	117	43	387	4387	4774
1981	149	78	117	43	387	4581	4968
1982	149	78	117	43	387	4686	5073
1983	149	78	117	43	387	4772	5159
1984	149	78	117	43	387	4772	5159
1985	149	78	117	43	387	4772	5159
1986	149	78	117	43	387	4772	5159
1987	149	78	117	43	387	4772	5159
1988	149	78	117	43	387	4772	5159
1989	149	78	117	43	387	4772	5159
1990	149	78	117	43	387	4772	5159
1991	149	78	117	43	387	4772	5159
1992	149	78	117	43	387	4772	5159
1993	149	78	117	43	387	4772	5159
1994	149	78	117	43	387	4772	5159
1995	149	78	117	43	387	4772	5159
1996	149	78	117	43	387	4772	5159
1997	149	78	117	43	387	4772	5159
1998	149	78	117	43	387	4772	5159
1999	149	78	117	43	387	4772	5159
2000	149	78	117	43	387	4772	5159

Table 11

GRADUATES AND PROJECTED GRADUATES

Year	*University of Illinois*	*Northwestern University*	*Loyola University*	*Southern Illinois University*	*Illinois Total*	*Other U.S. Schools*	*Total*
1960	81	90	79	0	250	3003	3253
1961	72	83	85	0	240	3050	3290
1962	76	79	94	0	249	2958	3207
1963	77	64	94	0	235	2998	3233
1964	83	64	87	0	234	2979	3213
1965	77	56	95	0	228	2953	3181
1966	75	55	72	0	202	2996	3198
1967	65	65	91	0	221	3139	3360
1968	93	71	77	0	241	3216	3457
1969	81	68	87	0	236	3197	3433
1970	88	66	78	0	232	3463	3695
1971	89	67	102	0	258	3523	3781
1972	90	84	113	0	287	3501	3788
1973	88	80	117	0	285	3634	3919
1974	88	78	117	0	283	3803	4086
1975	116	78	117	22	333	3949	4282
1976	149	78	117	22	366	4091	4457
1977	149	78	117	22	366	4218	4584
1978	149	78	117	22	366	4257	4623
1979	149	78	117	22	366	4315	4681
1980	149	78	117	43	387	4387	4774
1981	149	78	117	43	387	4581	4968
1982	149	78	117	43	387	4686	5073
1983	149	78	117	43	387	4772	5159
1984	149	78	117	43	387	4772	5159
1985	149	78	117	43	387	4772	5159
1986	149	78	117	43	387	4772	5159
1987	149	78	117	43	387	4772	5159
1988	149	78	117	43	387	4772	5159
1989	149	78	117	43	387	4772	5159
1990	149	78	117	43	387	4772	5159
1991	149	78	117	43	387	4772	5159
1992	149	78	117	43	387	4772	5159
1993	149	78	117	43	387	4772	5159
1994	149	78	117	43	387	4772	5159
1995	149	78	117	43	387	4772	5159
1996	149	78	117	43	387	4772	5159
1997	149	78	117	43	387	4772	5159
1998	149	78	117	43	387	4772	5159
1999	149	78	117	43	387	4772	5159
2000	149	78	117	43	387	4772	5159

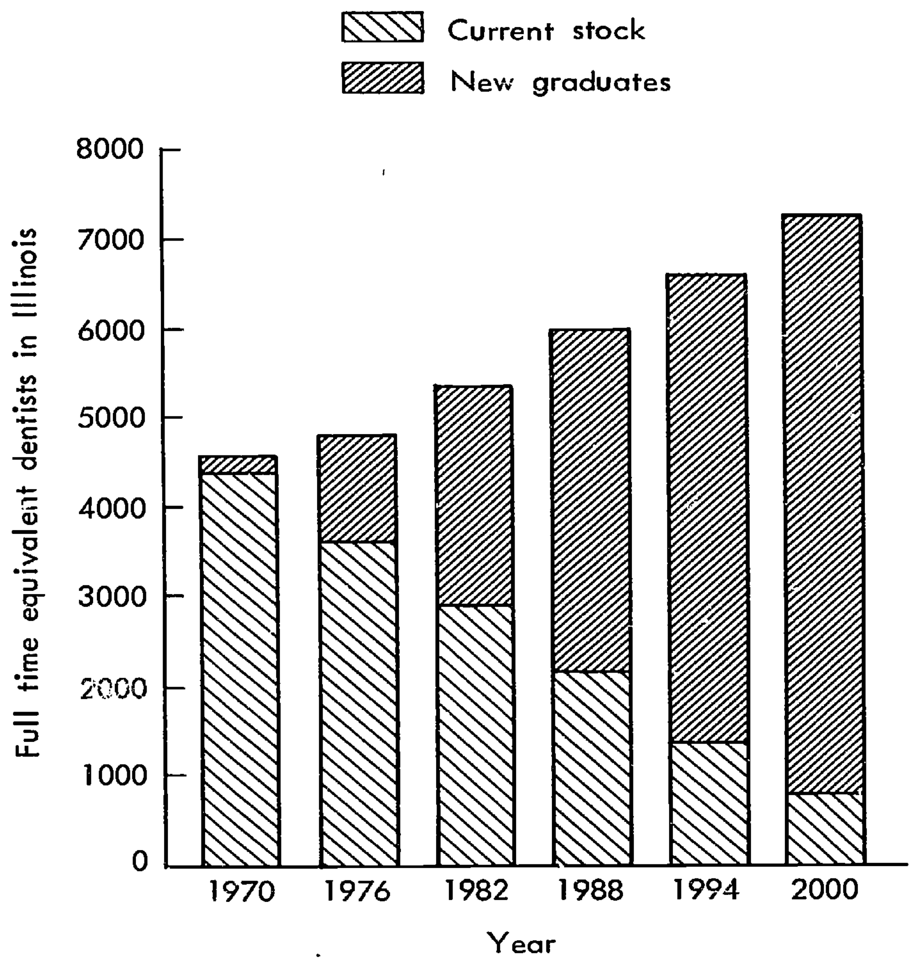


Fig. 9--Composition of total projected FTE dentists

It can be observed in the 30-year period, 1970 to 2000, that the planned enrollment increase, even assuming a level-off and large outmigration, can be expected to increase the number of dentists in the state by approximately 56 percent. Although this is a large increase, population projections indicate a significant increase in Illinois residents for the same period. Using 1970 census preliminary results and Illinois Department of Business and Economics population projections for 1980, the expected number of dentists per 100,000 population has been computed and is displayed in Fig. 10 by the line labeled planned enrollment. Due to the current age distribution with relatively large numbers in the older age brackets, the ratio of dentists to population is expected to

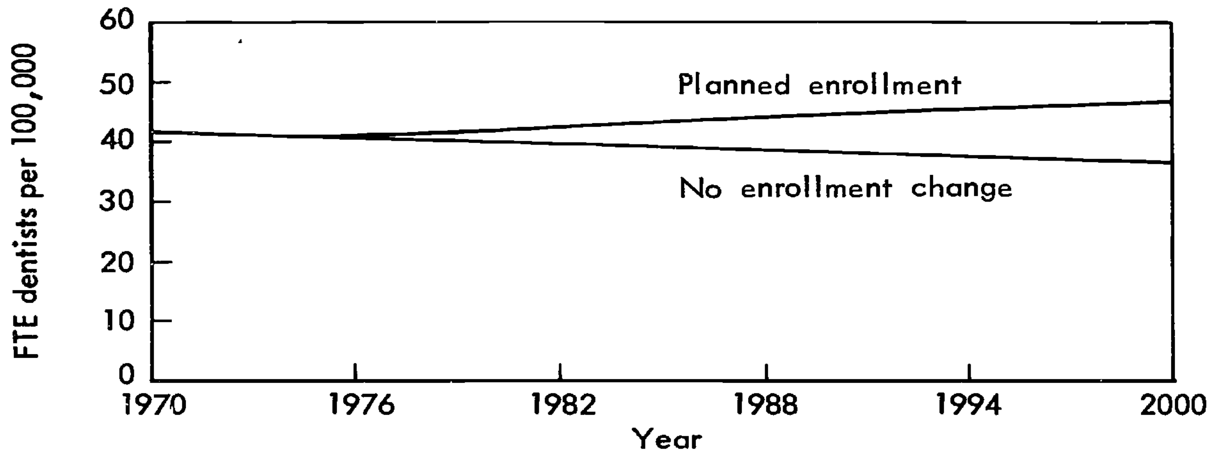


Fig. 10--Projected FTE dentists per 100,000 persons to year 2000

decrease through 1975, even though graduating classes have been in creasing in recent times and are planned to steadily increase through 1985. As these older Illinois dentists leave practice through death or retirement, the ratio will gradually improve, although not markedly. Over the 30-year period, it is expected that the ratio of dentists to population will rise from a low in 1975 of 40.9 to a high in 2000 of 46.2, a 13 percent increase.

If the proposed expansion does not take place, that is, if we assume new registration to be constant and at the 1970-71 level, the effect on the number of FTE dentists per 100,000 population is as shown by the line labeled "no enrollment change." Both curves are based on the assumption that past migration patterns remain unchanged.

Without the planned enrollment increase, the dentist-to-population ratio decreases steadily, going from 40.7 per 100,000 in 1975 to 40.0 per 100,000 in 1980.

VII. FUTURE MANPOWER REQUIREMENTS

Whether or not the estimated future dental manpower supply for the baseline case will be sufficient to meet the future demand for dental services will depend on many factors, including the future geographic distribution of dental manpower.

To forecast the future distribution, it is necessary to make certain assumptions concerning dentists' behavior. We shall make the following two key assumptions:

1. The 1969 pool of dentists will remain in their current county of residence for the forecast period.
2. Dentists added to the Illinois pool (by virtue of graduation from school) will distribute themselves in accordance with the 1969 county distribution.

Assumption (1) allows us to employ the supply equation separately for each county since each county is assumed to be a closed system, except for the inflow of new graduates. The second assumption defines the allocation of new graduates to each of the Illinois counties.

With a distributional forecast made in this manner, an analysis of dental manpower requirements similar to that performed for the year 1969 has been performed for the years 1980 and 1990. Figure 11 displays the total dentist deficit, Case 1 and Case 2, for the years 1980 and 1990. Despite a considerable change in both population and dental manpower, the total dentist deficit changes relatively little from 1980 to 1990. Furthermore, a comparison with Fig. 1 will indicate that only a small change in the deficit should be expected from 1969 to 1980. For a service level consistent with the 1969 state average (1.5 visits per year) the dentist deficit is approximately 450 in 1969, expected to be 530 in 1980, and 590 in 1990. Thus, although the aggregate dentist-to-population ratio appears to be improving slightly, imbalances in distribution could lead to a moderately increased need for additional dentists at current service levels. It appears clear, however, that any future marked increase in manpower requirements will more likely result from a change in the demand for dental care than a change in the per capita supply.

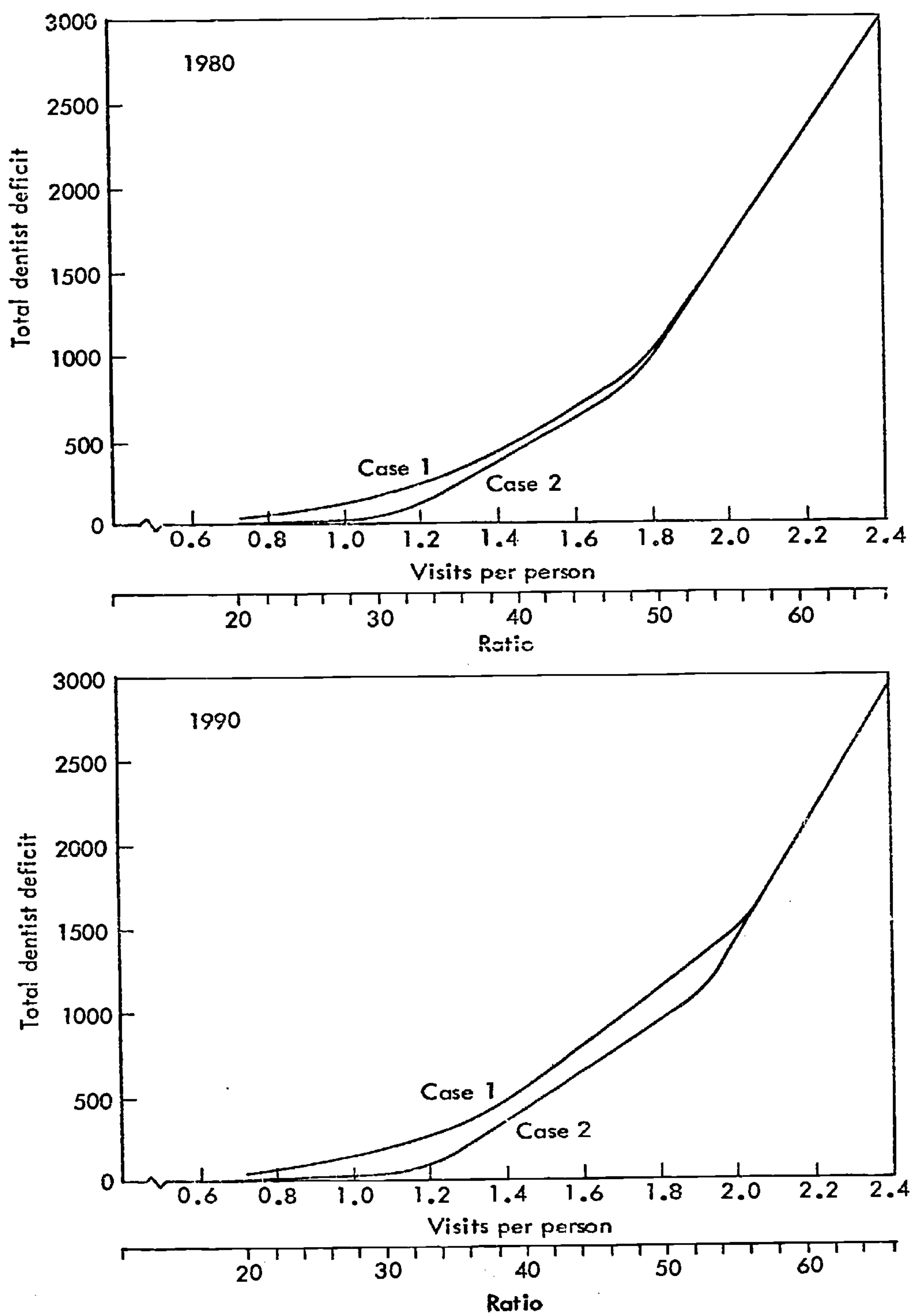


Fig. 11--Forecast of total Illinois dentist deficit in 1980 and 1990, Case 1 and Case 2

Table 12 shows projected visits per person per year as determined from projected mean family income in Illinois and a recent estimate of the relationship between income and dental visits.* Taking the middle

Table 12

ESTIMATED ANNUAL DENTIST VISITS PER PERSON IN ILLINOIS[a]

Year	*Low*[b]	*Middle*[b]	*High*[b]
1970	1.49	1.75	2.01
1980	1.74	2.02	2.31
1990	1.99	2.30	2.60
2000	2.20	2.53	2.85

[a]Based on estimated mean family income at 1960 prices.

[b]Mean family income is estimated from distributions showing the percent of families in each income class. "Low" assumes that each class mean is at the low end of the class range, "High" at the high end, and "Middle" at the midpoint of the class range. Overall mean family income is the weighted sum of the class means.

range figure of 2.02 visits in 1980, we have, from Fig. 11, a deficit of approximately 1700 dentists, and for 1990, a deficit of 2600 based on a service level of 2.3. Although it is not clear that consumption of dental services can be predicted on the basis of changes in mean family income, future increases in income will undoubtedly increase demand.

To better understand the significance of these potential dentist

*Income projections are based on *Projection of Income Size Class Distributions of Consumer Units, by State, for 1964, 1969, 1974, and 1976*, Regional Economic Projections Series, Report No. 64-III, Center for Economic Projections, National Planning Association, Washington, D.C. The relationship between dental visits and income was provided by Roger B. Cole, Division of Dental Health, Public Health Service, Department of Health, Education and Welfare.

deficits, the percent of the required number of patient visits that cannot be provided for reasons of supply or distribution is shown as a function of the desired service level in Fig. 12. Using the service levels of 2.02 for 1980 and 2.3 for 1990, we find deficits of about 25 percent and 29 percent, respectively.

Figure 13 shows the dentist deficits for 1980 and 1990 assuming that additional dentists would distribute themselves in accordance with the 1969 distribution. As was the case in analyzing the status of dental manpower in 1969, these curves indicate considerably larger requirements than those of Fig. 12, thus pointing out the effect of the expected persistence of the uneven dentist distribution in Illinois. Table 13 gives the forecast ratios and population by region, and Fig. 14 displays the regional analysis of dentist deficits for 1980. In general, these figures and tables appear quite similar to those developed for the 1969 distribution of dentists. The magnitude of the deficits appears stable while the dentist-to-population ratios are improving slightly with the passage of time.

Table 13

STATUS OF ILLINOIS DENTIST SUPPLY IN 1980 AND 1990

Region and Year	*FTE Dentists*	*Population (in thousands)*	*FTE Dentists per 100,000*
1980			
1	3,778.46	7,863.0	48.05
2	430.48	1,266.0	34.00
3	190.20	650.0	29.88
4	40.43	159.0	25.43
5	166.99	466.0	35.83
6	171.58	551.0	31.14
7	372.45	1,375.0	27.09
State	5,154.60	12,330.0	41.81
1990			
1	4,545.51	8,720.0	52.13
2	503.57	1,442.2	34.92
3	228.32	722.9	31.59
4	49.03	195.8	25.04
5	196.77	539.0	36.50
6	204.06	644.2	31.67
7	451.26	1,555.5	29.01
State	6,178.53	13,819.7	44.71

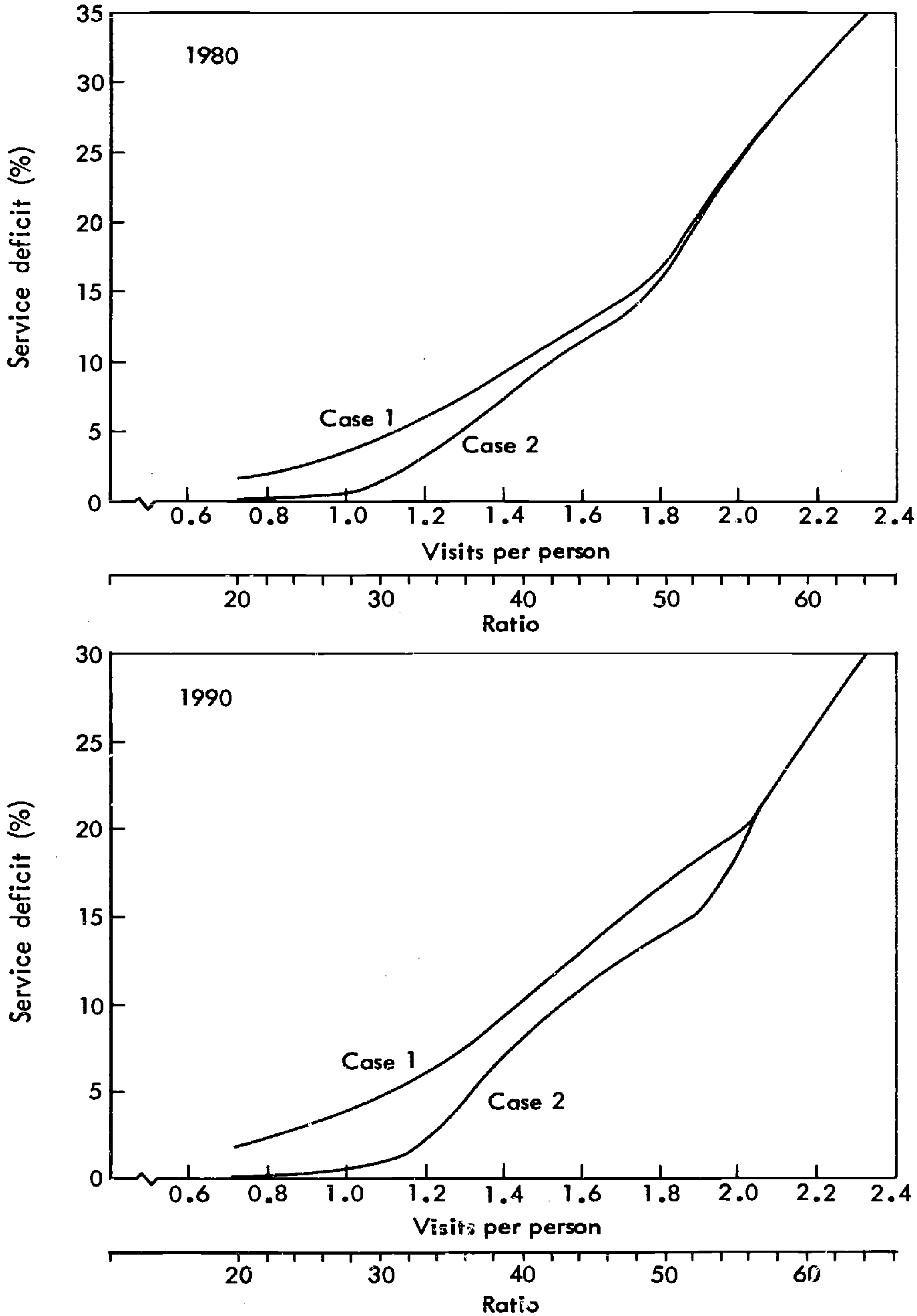


Fig. 12--Dental visits not provided due to dental manpower deficit, 1980 and 1990, Case 1 and Case 2

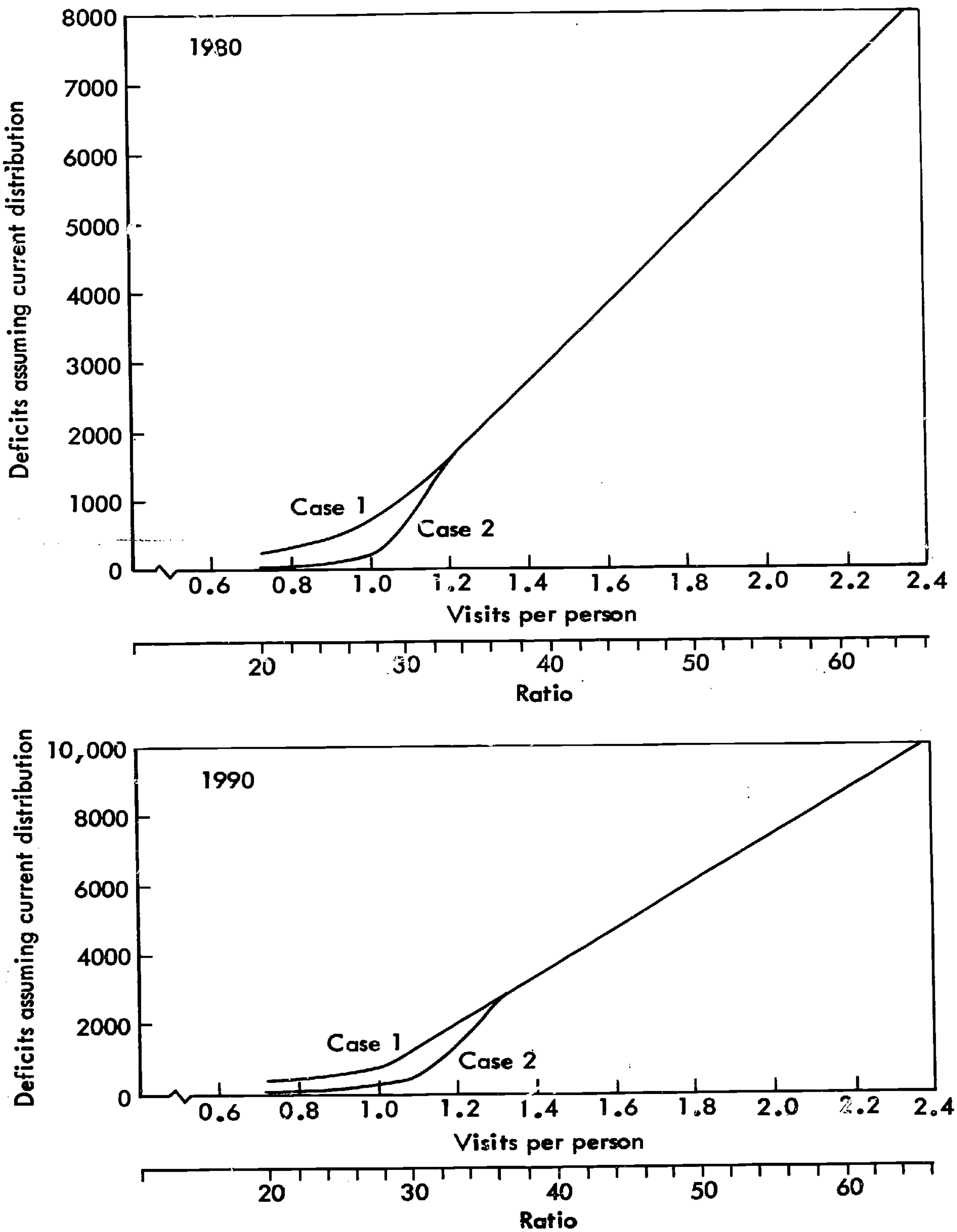
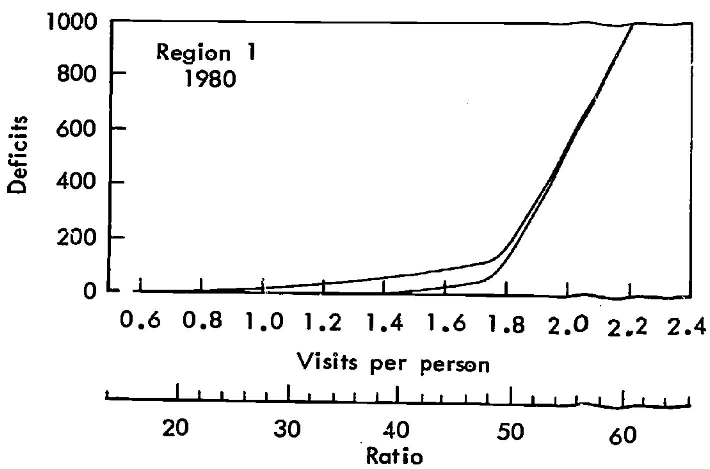
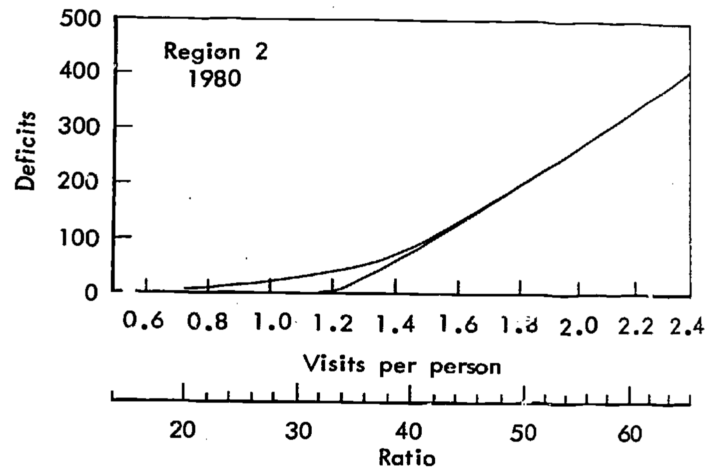


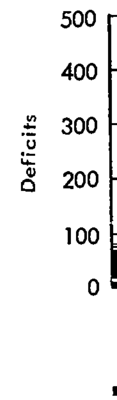
Fig. 13--Dentist deficit in 1980 and 1990 assuming distribution as per 1969, Case 1 and Case 2



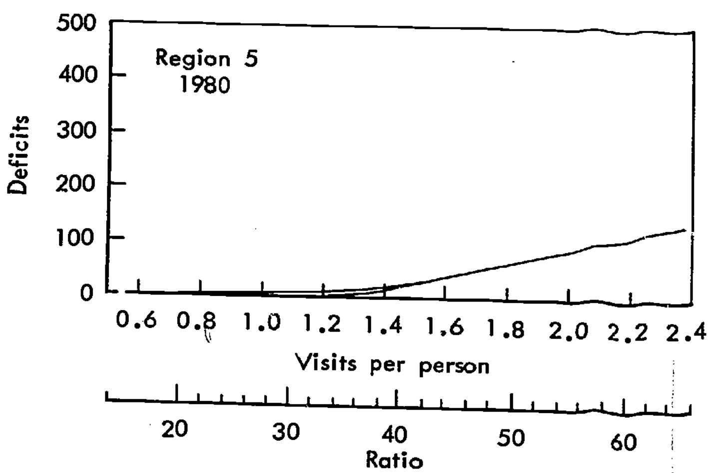
Region 1
1980
Deficits
1000
800
600
400
200
0
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
20 30 40 50 60
Ratio



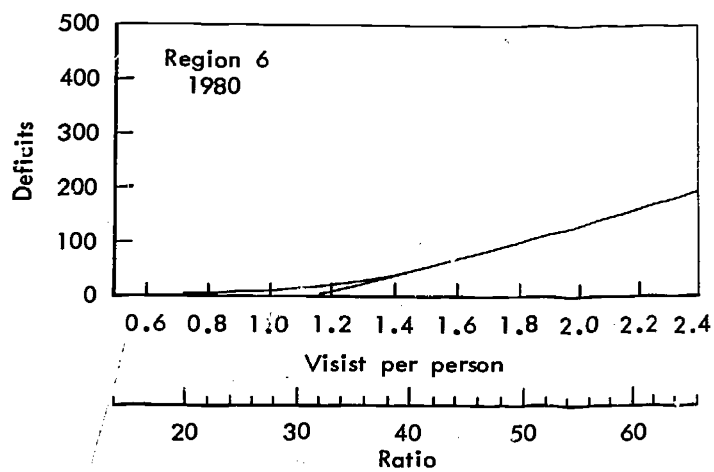
Region 2
1980
Deficits
500
400
300
200
100
0
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
20 30 40 50 60
Ratio



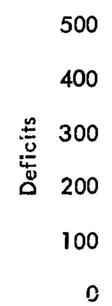
Deficits
500
400
300
200
100
0



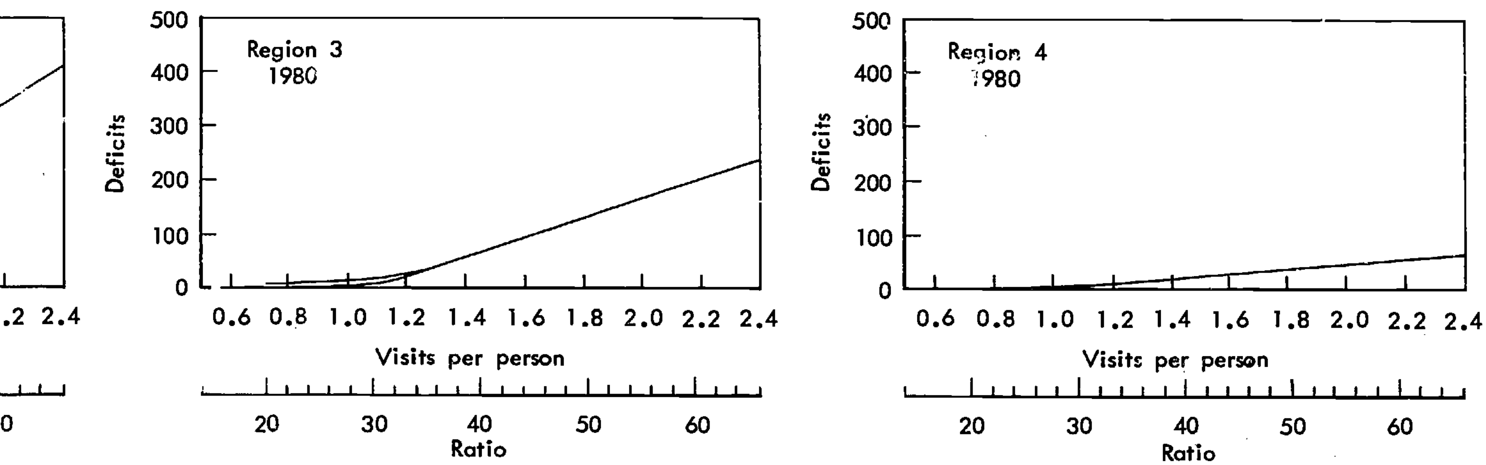
Region 5
1980
Deficits
500
400
300
200
100
0
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visits per person
20 30 40 50 60
Ratio



Region 6
1980
Deficits
500
400
300
200
100
0
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Visist per person
20 30 40 50 60
Ratio



Deficits
500
400
300
200
100
0



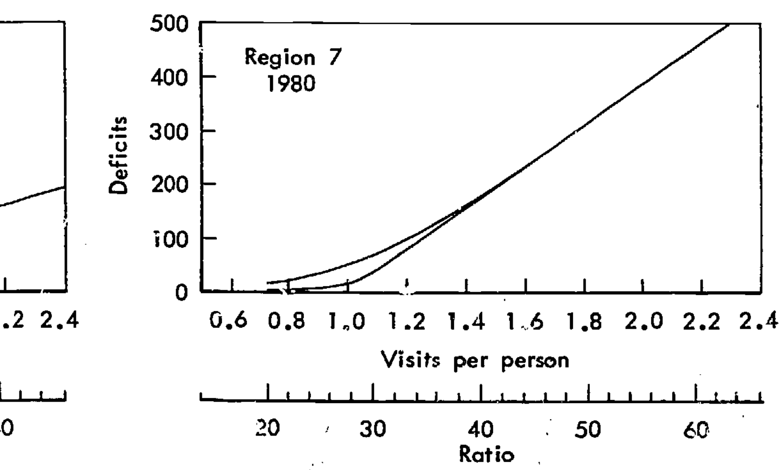


Fig. 14--Total 1980 Illinois dentist deficit by region, Case 1 and Case 2

Note: The deficit scale in Region 1 is twice that in all others.

VIII. CONCLUSIONS AND POLICY ISSUES

Based on the assumptions of this analysis, it appears that the current plans to expand dental schools in Illinois will do little more than keep pace with the forecasted increase in Illinois population. Projected dentist deficits for 1980 and 1990 are very close to those of 1969, and the dentist-to-population ratio will improve only 7 percent by the year 1990. Thus, if the demand for dental services remains what it is today, we can expect dental care in Illinois to be quite similar in its quantity per capita to that of 1969 for the next 20 years or so, barring, of course, drastic changes in the delivery of dental services. In this case, if there is to be a significant decrease in the availablity of dental care in Illinois, it will occur because of a change in the demand for services.

Projected demand for dental care based on future increases in mean family income leads to large deficits in the Illinois dental manpower pool--1700 dentists in 1980 and 2600 in 1990. Although the current relationship between family income and consumption of dental services cannot be accepted with assurance for forecasting purposes, forecasts made on this basis do have some merit. Certainly, for many reasons, including larger incomes, we do expect effective demand to increase. Thus, we believe that Illinois must anticipate and plan for a future expansion of dental service.

How should this expansion be undertaken? One way for a state such as Illinois to expand future dental service is to increase the future enrollment in dental schools above currently planned levels. This is certainly effective, but in itself, considering the magnitude of the increase that may be required, very likely impractical. In Fig. 15a, the percent increase in the currently planned graduating classes that would be required to satisfy various levels of demand in 1980 and 1990 is displayed. The increase is assumed to begin in 1975, the first year possible, given a change in the first-year class beginning in 1971. To provide an average level of 2.02 visits per year per person by 1980 would require a 210 percent increase in the Illinois graduating classes for the years 1975 to 1980. To provide 2.3 visits in 1990 would require almost a doubling of the currently planned enrollments. It seems reasonable, therefore, to expect that future demands for dental service of this magnitude will not be met by changes in graduation rates alone.

As an alternative or supplement to enlarging the dental education program, Illinois planners must consider the possibility of altering the present migration patterns of dental school graduates. It will be recalled from Fig. 7 that in the steady state, only 20 percent of the graduates of Northwestern ultimately practice in Illinois--the comparable figures for the University of Illinois and Loyola are 66 and 43 percent, respectively. From the point of view of increasing the future supply of Illinois dentists, a percentage increase in the inmigration rates (associated with an institution) has the same effect as the same percentage increase in its enrollment. Figure 15b shows the percentage increase in inmigration rates necessary to eliminate the Illinois dentist deficit by 1980 and 1990. In computing Fig. 15b, the inmigration rates for each institution (including out of state institutions) were increased by the stated percentage commencing in 1970. In no case, however, was the total inmigration rate for an institution allowed to exceed unity. From a comparison of Figs. 15a and 15b, it is apparent that in terms of percentage alteration, an increase in net inmigration is somewhat more effective in reducing a deficit than a corresponding increase in enrollment. This occurs because a change in the number of graduates comes about 4 years after a change in the number of first-year students. Nevertheless, the achievement of forecasted service levels of 2.02 in 1980 and 2.3 in 1990, through altering only the migration rates, requires increases on the order of 100 percent.

Finally, as a means of increasing the future quantity of dental services available, there is the possibility of altering the delivery of dental care itself. We will not explore this subject here other than to point out the implications of changes in dentist productivity that might result from more efficient means of delivery. Figure 16 shows the total Illinois dentist deficit in 1980 and 1990 as a function of various levels of productivity and service. Dentist productivity has been defined previously, where a productivity of 1 indicates the ability to provide care for 3629 visits per year. In a recent study,

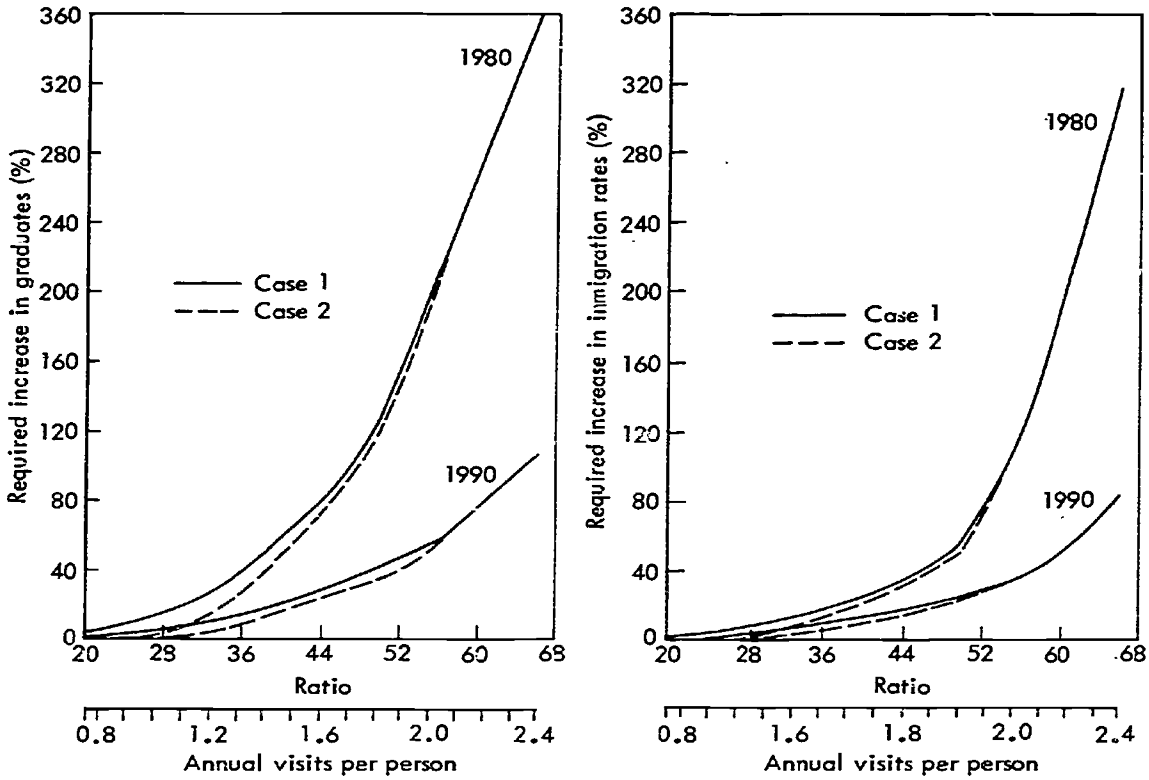


Fig. 15a--Increase graduates *Fig. 15b--Increase inmigrations*

Fig. 15--Two alternatives for meeting increased demand for dental services, 1980 and 1990

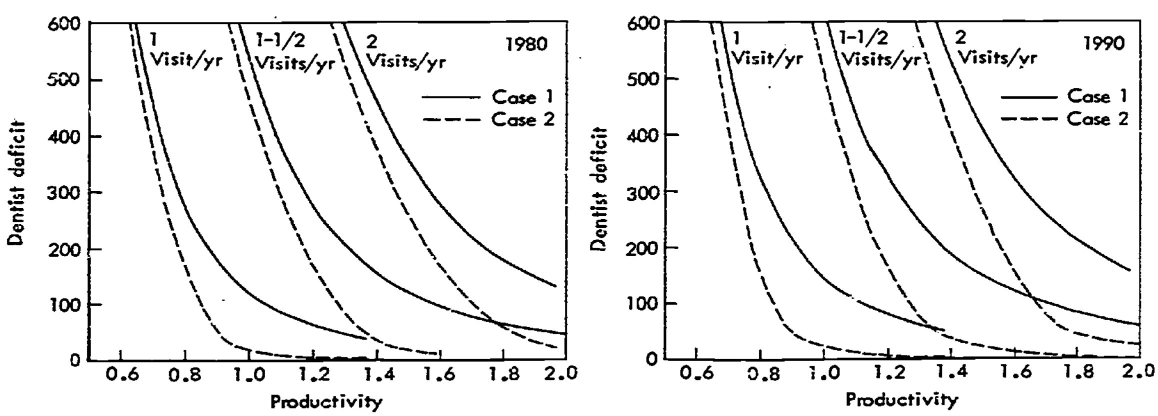


Fig. 16--Effect of increasing dentist productivity at various service levels, 1980 and 1990

it was observed that in terms of patients seen, the use of four assistants performing expanded functions increased dentist productivity by 41 percent.* What would be the implication of such a change in productivity? From Fig. 16 we see a dentist deficit of approximately 510 for a level of 1.5 visits per year in 1980 and a productivity of 1. Expanding the function of dental assistants to increase dentist productivity to 1.41 would reduce the deficit to between 30 and 150. A similar comparison for 1990 at a level of 2 visits per year indicates a reduction in the dentist deficit of approximately 800.

Of the approaches mentioned here for increasing the ability of Illinois dentists to meet future demands for dental care, no single approach will be likely to be sufficient in itself. Rather, it seems that Illinois policymakers will have to rely on many methods to meet what is an almost certain increase in the per capita demand for services.

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*Based on a draft report by S. Lotzkar, et al., op. cit.

The growth in dental auxiliary education in Illinois relative to undergraduate dental education for the period of 1965-69 is shown in the following:

	1965	*1966*	*1967*	*1968*	*1969*
Dental Hygiene	48	46	48		95
Dental Assisting	39	49	65		130
Dental Laboratory Technology	21	27	16		21
Total All Auxiliaries	108	122	129		246
Total Dentists	237	201	216	245	238

While the annual number of graduating dentists has remained relatively constant for the period shown, the number of auxiliaries graduated annually has more than doubled, having reached a graduation level equivalent to that for the dentists. Auxiliary programs will, however, have to continue to expand or increase in number in order to keep pace with the dentists, given the undergraduate dental education changes already discussed.

Appendix A

THE STUDENT FLOW MODEL

Student flow models describe the progress of students through an educational process by mathematically representing the structural components of that process and the relationships linking the components. The structural components are a series of "states" through which students must progress. Once the structural components of the process have been defined, the relationships between them must be specified. These relationships take the form of ways in which the students may enter or leave each of the defined states. A separate set of states and paths are used for each type of student.

The educational process as described above is a specific case of a general class known as Markov Processes. In this case, the states are levels in the educational program, including a specification of the time period at that level. For example, for a 4-year program, there are six possible states:

State	*Description*
1	First level
2	Second level
3	Third level
4	Fourth level
5	Graduated from system
6	Dropped out of system

The paths leading into each state can be defined as:

1. New registration.
2. Advanced standing placement.
3. Promotion to that state.
4. Repetition of that state.

Similarly, the paths for leaving each state can be defined as:

1. Promotion from that state.
2. Discharge from the system.

Each of the above paths can be viewed as links between the various states. Figure 17 shows a cross referencing for the paths available for entrance or exit for each of the six states.

	States					
	1st Level	2nd Level	3d Level	4th Level	Graduated	Dropped Out
Paths for entrance						
Registration	X					
Advanced standing		X	X	X		
Promotion to		X	X	X	X	
Repetition of	X	X	X	X		
Discharge						X
Paths for exit						
Promotion from	X	X	X	X		
Discharge	X	X	X	X		

Fig. 17--Links between states

Using these definitions, the following equation gives a description of enrollment or number of students at level ℓ during time t,

$$E_{(t,\ell)} = R_{(t,\ell)} + RS_{(t,\ell)} + PS_{(t,\ell)} + AS_{(t,\ell)}, \tag{1}$$

where $E_{(t,\ell)}$ = enrollment in level ℓ during time t,
$R_{(t,\ell)}$ = new first year students in level ℓ during time t,
$RS_{(t,\ell)}$ = students repeating level ℓ during time t,
$PS_{(t,\ell)}$ = students promoted into level ℓ for time t,
$AS_{(t,\ell)}$ = students with advanced placement into level ℓ for time t.

The specific equation for each level can be derived using only the conditions applicable to that level. For example, promoted students, $PS_{(t,\ell)}$, and students with advanced placements, $AS_{(t,\ell)}$, would, by definition, drop from the equation for first level students. Considering this and other simplifications of the general formula, Eq. (1), the following pair of specific equations can be derived for the first four levels:

<u>Level 1 Computations (ℓ = 1)</u>

$$E_{(t,\ell)} = R_{(t,\ell)} + RS_{(t,\ell)}; \tag{2}$$

<u>Level 2, 3, or 4 Computations (ℓ = 2, 3, 4)</u>

$$E_{(t,\ell)} = RS_{(t,\ell)} + PS_{(t,\ell)} + AS_{(t,\ell)}. \tag{3}$$

The time dependence of the student flows can be seen as we expand Eqs. (2) and (3) to explicitly show how the terms of these equations relate to enrollment in prior levels during preceding years. Starting with Eq. (2), $RS_{(t,\ell)}$--the number of students repeating level ℓ during academic year t--is some fraction of the number of students enrolled in level ℓ during the previous year. Viewing this fraction as a probability that students will repeat level ℓ, the following equation is obtained:

$$RS_{(t,\ell)} = p_{(\ell,\ell)} \times E_{(t-1,\ell)}, \tag{4}$$

where $RS_{(t,\ell)}$ = students repeating level ℓ during academic year t,
$p_{(\ell,\ell)}$ = probability that a student will repeat level ℓ,
$E_{(t-1,\ell)}$ = enrollment in level ℓ during academic year $t - 1$.

Similarly, $PS_{(t,\ell)}$--the number of students promoted into level ℓ for academic year t--is a fraction of the number of students in the next lower level during the previous year, and the number of students promoted to level ℓ in time t can be expressed as

$$PS_{(t,\ell)} = p_{(\ell-1,\ell)} \times E_{(t-1,\ell-1)}, \tag{5}$$

where $PS_{(t,\ell)}$ = students promoted into level ℓ for academic year t,
$p_{(\ell-1,\ell)}$ = probability of promotion from level $\ell - 1$ to level ℓ,
$E_{(t-1,\ell-1)}$ = enrollment in level $\ell - 1$ during academic year $t - 1$.

Substituting Eqs. (4) and (5) into Eqs. (2) and (3), the following equations are obtained:

<u>Level 1 Computations ($\ell = 1$)</u>

$$E_{(t,\ell)} = R_{(t,\ell)} + [p_{(\ell,\ell)} \times E_{(t-1,\ell)}]; \tag{6}$$

<u>Level 2, 3, or 4 Computations (ℓ = 2, 3, or 4)</u>

$$E_{(t,\ell)} = [p_{(\ell,\ell)} \times E_{(t-1,\ell)}] + [p_{(\ell-1,\ell)} \times E_{(t-1,\ell-1)}] + AS_{(t,\ell)}. \tag{7}$$

These are the basic equations used in the computation of enrollment at the various intermediate levels within the undergraduate educational process. Using these equations, it is possible to predict the progress of some specified group of new first year students from one level to the next. At each transition from a level, students will either progress to the next level, repeat the present level, or drop from the system.* By moving the group of students from level to level by means of the equations specified above, one can predict the enrollment at each of the intermediate levels in the process.

In addition to the number of students at each of the intermediate levels, a major output of the student flow model is the number of graduates that can be expected from a specified group of new students. Since the student group specified will already have been moved through intermediate levels in the system, the number of graduates expected can be expressed simply as a fraction of the enrollment in level 4--fourth year students.

$$G_{(t)} = p_{(4,5)} \times E_{(t,4)}, \tag{8}$$

where $G_{(t)}$ = number of graduates produced at the end of time t,

$p_{(4,5)}$ = probability of graduation,

$E_{(t,4)}$ = enrollment in level 4 during time t.

The student flow model, therefore, by using Eqs. (6), (7), and (8), can describe the movement of a group of entering students through the educational process and estimate the number of students at each intermediate level and the number of graduates produced, allowing f-- repeats and advanced standing admissions.

By performing this operation for each of a number of entering student groups, specified for each year in the planning period, the model provides a basis for analyzing various aspects of student flow in addition to providing estimates of enrollment and graduates. Consider, for example, the effect of repeating students. The immediate effect

*Those students dropping out are not explicitly shown, but this fraction is 1 minus the fraction progressing and repeating.

of "repeats" at a given level is to increase the enrollment at that level and decrease enrollment in the next level. An additional impact of students repeating segments of previous levels will be observed as a slowing of student flow. This slowing will most commonly manifest itself during the latter portion of a student's education when prior obligations force the student to relinquish his position in the normal flow. For institutions of higher education, the number of students required to repeat an entire level will be small. More often, students will advance to the next level with an obligation to repeat only a portion of the previous level. Consequently, students appear to repeat the third or fourth year even though the necessity for such repetition was generated earlier in their progression.

TRANSITION PROBABILITIES

A consolidated list of the paths into and from the various states listed on page 49 shows that there are five distinct possibilities defined for the flow model.

1. New registration.
2. Advanced standing placement.
3. Promotion.
4. Repetition.
5. Discharge.

New registration and advanced standing placement are viewed as being determined outside the model. The remaining three paths are part of the model and treated probabilistically as transition probabilities.

For each student in the system, the full set of possible outcomes is defined by the three transition paths so that

$$p(\ell, \ell + 1) + p(\ell, \ell) + p(\ell, 6) \equiv 1, \qquad (9)$$

where $p(\ell, \ell + 1)$ = the probability of being promoted,

$p(\ell, \ell)$ = the probability of repeating,

$p(\ell, 6)$ = the probability of discharge.

The probability of discharge will be treated residually since

$$p(\ell, 6) \equiv 1 - p(\ell, \ell + 1) - p(\ell, \ell). \qquad (10)$$

Further, the following major assumptions will be made:

1. The probabilities for each student are independent and identically distributed.
2. The parameters of the probability distributions are stationary from year to year.

The second assumption is somewhat restrictive since the magnitude of a given set of transition probabilities is obviously determined by some set of characteristics present in the subject student population. Some student flow models attempt to take these "motivating mechanisms"* into account in the estimation of transition probabilities. Introducing this assumption, however, greatly reduces the number of parameters to be estimated and the data requirements. Second, unless the administrative policies of the schools or the general motivational characteristics of the students admitted change significantly, the estimates should be reasonably accurate.

PROBABILITY OF PROMOTION

To establish the probability distributions of promotion, we introduce the following notation and concepts. Let

$$x(i, \ell, t) = \begin{cases} 1 \text{ if the } i\text{th student in level } \ell \text{ at time} \\ t \text{ is promoted to level } \ell + 1. \\ \text{Zero otherwise (repeats or leaves system).} \end{cases} \qquad (11)$$

The outcome of zero or one, $x(i, \ell, t)$ may be viewed as a random variable with a Bernoulli distribution with mean p and variance $p(1 - p)$. Defining $N(\ell, t)$ as the number of students in level ℓ at time t,

$$E_p(\ell + 1, t + 1) = \sum_{i=1}^{N(\ell,t)} x(i, \ell, t) \qquad (12)$$

*Alper, Armitage, Smith, "Educational Models, Manpower, Planning and Control," *Operations Research Quarterly*, Vol. 18, No. 2, June 1967.

is also a random variable with mean $N(\ell, t) \times p$ and variance $N(\ell, t) \times p \times (1 - p)$, where E_p represents those students that were promoted.

Now, given our assumption of stationarity, an estimator of the probability of promotion, $\hat{p}(\ell, \ell + 1)$, can be defined as

$$\hat{p}(\ell, \ell + 1) = \frac{\sum_{t=1}^{(n-1)} E_p(\ell + 1, t + 1)}{\sum_{t=1}^{(n-1)} N(\ell, t)} \qquad (13)$$

where n is the number of years or observations. The estimator is also a random variable with mean $p(\ell, \ell + 1)$ and variance $p(\ell, \ell + 1) \times [1 - p(\ell, \ell + 1)]/\Sigma_{t=1}^{(n-1)} N(\ell, t)$.

The central limit theorem states that the sum of independent and identically distributed random variables approaches the normal distribution as the number of variables in the sum approaches infinity. Therefore, for "large" N the distribution of $p(\ell, \ell + 1)$ will be approximately normal.*

PROBABILITY OF REPEATING

Let us redefine the possible outcomes for time $(t + 1)$ for student i as follows:

1. He stays in the system but repeats.
2. He drops out of the system or is promoted.

If we assign a value of 1 to outcome 1 and a value of 0 to outcome 2, then

$$E_r(\ell + 1, t + 1) = \sum_{i=1}^{N(\ell+1,t)} x(i, \ell + 1, t) \qquad (14)$$

*The approximation is good when the range of application is limited by the inequality $N \times p \times (1 - p) > 9$. Albert H. Bowker and Gerald J. Liberman, *Engineering Statistics*, Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1959, p. 90.

is again a random variable with mean $N(\ell + 1, t) \times p$ and variance $N(\ell + 1, t) \times p \times (1 - p)$. In this case, E_r are those students enrolled that repeated.

The estimator of the probability of repeating can now be defined as

$$\hat{p}(\ell, \ell) = \frac{\sum_{t=1}^{(n-1)} E_r(\ell + 1, t + 1)}{\sum_{t=1}^{(n-1)} N(\ell + 1, t)}. \qquad (15)$$

This estimator will again be a random variable, approximately normal for large N, with mean $p(\ell, \ell)$ and variance $p(\ell, \ell)[1 - p(\ell, \ell)]/\Sigma_{t=1}^{(n-1)} N(\ell + 1, t)$.

AGGREGATED TRANSITION PROBABILITY

If only data on total enrollment by year are available, it is possible to estimate an aggregated transition probability that should also be reasonably accurate as long as there are no significant changes in school policy. In this case, the two possible outcomes are defined as follows:

1. The student is enrolled.
2. The student is not enrolled.

Again, a value of 1 is given to outcome 1 and a value of 0 to outcome 2.

The estimator of the aggregated transition probability is then defined as

$$\hat{P}(\ell, \ell + 1) = \frac{\sum_{t=1}^{(n-1)} E(\ell + 1, t + 1)}{\sum_{t=1}^{(n-1)} N(\ell, t)}, \qquad (16)$$

where E is total enrollment. In general, it will also be assumed that this is approximately a normally distributed random variable with mean P and variance $P(1 - P)/\Sigma_{t=1}^{(n-1)} N(\ell, t)$. However, it should be noted that the validity of this assumption is greatly weakened in cases where advanced standing admittance is significant.

CONFIDENCE INTERVALS

Also calculated are 95 percent confidence intervals for all probabilities. To calculate the confidence intervals, we have used the normal approximation to the binomial distribution. Use of the binomial distribution would be more accurate, but it presents problems due to the large numbers involved and the computation time required. The confidence intervals are calculated as follows: let

p = the estimated probability;
n = the sample size (number of students) on which p is based;
d = the standard deviation of p.

An unbiased estimate of d is

$$d = \sqrt{\frac{p(1 - p)}{n - 1}},$$

and the 95 percent confidence interval for p is $(p - 1.96d) \le p \le (p + 1.96d)$.

Appendix B

TECHNICAL APPENDIX FOR MANPOWER STATUS AND SUPPLY

OPTIMUM ALLOCATION OF DENTISTS

A simple example should help clarify what is meant by an optimum allocation. In Fig. 18, four counties are represented as A, B, C, and D. Within each county, the dentist surplus (+) or deficit (-) is shown as calculated from an assumed ratio. One possible allocation of dentists for these four counties is as follows: County C loans 5 to County B, leaving a deficit in County B of 5. This deficit is then removed by an allocation of 5 dentists from County A. The net result is shown in Fig. 19.

A	B	C	D
+10	-10	+5	-10

Fig. 18--Hypothetical dentist deficits for four counties

A	B	C	D
+5	0	0	-10

Fig. 19--Dentist deficit after allocation

Since A is not adjacent to D, no further loaning can take place. This allocation leads to a requirement of 10 dentists. An optimum allocation leads to a requirement of only 5 dentists. County A loans 10 to B; C loans 5 to D.

For a layout of counties more complex than the simple example, the way to determine the general solution for an optimum allocation is not altogether clear. The counties of Illinois are such a case. Although the general algorithm that guarantees a solution to all conceivable layouts of counties has not been determined, we have established certain necessary conditions for optimality that are, from a practical point of view, almost always sufficient. In the rare instance where these conditions do not yield a total solution, it has been possible to resolve remaining uncertainties by trial and error. The four conditions employed are as follows:

I. If a county has a deficit:
   A. It borrows all necessary dentists if it has only one neighbor with a surplus;
   B. It borrows all necessary surplus dentists from its neighbors provided that this exhausts each of its neighbors' surplus.

II. If a county has a surplus:
   A. It loans all surplus dentists necessary if it has only one neighbor with a deficit;
   B. It loans all surplus dentists necessary to its neighbors provided that this fills each of its neighbors' deficit.

In these conditions, the word "necessary" should be interpreted as "necessary to fill a deficit." Thus, no county borrows more dentists than are required to fill its deficit, and no county loans more than its surplus dentists. It should be noted that there exists a dualism between the first two and second two conditions. This occurs because the problem of maximizing the number of deficits filled (IA and IB) is equivalent to the problem of maximizing the number of dentists loaned (IIA and IIB).

Only conditions IA and IB will be discussed, the remaining conditions being established by the dual arguments. Condition IA states that a county with a deficit and only one neighbor with a surplus borrows to reduce the deficit as much as possible from that neighbor. Suppose a county with such a deficit did not borrow from its only choice. Then the dentists could be used no more effectively since they can only reduce a deficit in the amount of their number. The question is: Does the borrowing by this county affect the ability of other counties to lend? It cannot, since this county can borrow from only one source. Therefore, no other allocation could reduce the total deficit more.

Condition IB states that if a county in attempting to fill its deficit exhausts the surplus of all its neighbors, the resulting allocation is optimal. The argument supporting this condition is similar to the above. Since only the neighbors of such a county can lend dentists to fill its deficit, its being filled (partially or totally) does not affect the number or quantity of deficits available to the nonneighboring counties with a surplus. Furthermore, the dentists used to fill such a deficit could be used with no more reduction in the total deficit if they were allocated elsewhere. However, any allocation to another county with a deficit by the neighbors could only serve to reduce the options for allocation possessed by the other counties with a surplus. Thus, condition IB insures an optimal allocation.

DERIVATION OF THE SUPPLY EQUATION

To put the ideas of retirement, migration, and probability of death into mathematical form, we make the following definitions: Let

$D(i, y)$ = number of dentists in year y that are i years of age,

$I(i, j, y)$ = number of dental students that graduate from the jth institution in year y and are i years of age,

$a_k(i, j, y)$ = net fraction of graduates from jth institution, i years old at graduation, that take up practice in Illinois k years after graduation in year y,

$p(i, y)$ = probability of dying during year y for dentists of age i,

$r(i, y)$ = fraction of dentists i years old who will retire during year y.

The quantity $a_k(i, j, y)$ deserves some comment. When $a_k(i, j, y)$ is positive and j is an Illinois institution, a represents the inflow of new graduates. Under the same circumstances, if j stands for an out-of-state institution, then a corresponds to an inmigration. When $a_k(i, j, y)$ is negative, it represents outmigration. With these definitions, the supply equation is given by

$$D(i, y + 1) = D(i - 1, y)[1 - p(i - 1, y)][1 - r(i - 1, y)] + \sum_{j=1}^{M} \sum_{k=1}^{N} a_k(i - k, j, y + 1)I(i - k, j, y - k + 1), \quad (17)$$

where M is the number of relevant institutions and N is the number of years since graduation after which migration ceases.

The first term of Eq. (17) represents those Illinois dentists who will practice in year $y + 1$ and who were practicing in Illinois in year y. The remaining terms account for new entrants through graduation or inmigration and for outmigration. It should be observed that Eq. (17) is completely general in the sense that for any realizable set of dentist populations $[D(i, y), D(i, y + 1), D(i, y + 2), \ldots]$ and graduates $[I(i, j, y), I(i, j, y + 1), I(i, j, y + 2), \ldots]$ there exist values of the parameters, a, p, r, such that the equation holds. Equation (17) is, however, too general for most applications since its use requires the estimation of a prohibitively large number of parameters. In order to overcome this difficulty, we have made certain simplifying assumptions as follows:

1. Death, retirement, and migration rates are unchanging with respect to the calendar year.
2. Migration rates are only a function of years-since-graduation, i.e., not age dependent.
3. The age distribution of each graduating class is the same and given by $b(i)$, where $b(i)$ equals that fraction of the class that graduates at age i.

With these assumptions, Eq. (17) becomes

$$D(i, y + 1) = D(i - 1, y)[1 - p(i - 1)][1 - r(i - 1)] + \sum_{j=1}^{M} \sum_{k=0}^{N} a_k(j)b(i - k)I(j, y - k + 1). \qquad (18)$$

Once the parameters have been estimated, Eq. (18) can be solved recursively for future dentist populations. That is, with the number of dentists of age $i - 1$ in year y, Eq. (18) gives the number of age i in year $y + 1$, which in turn gives the number in year $y + 2$, and so on.

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