A SEMI-MARKOV MODEL FOR PRIMARY HEALTH CARE MANPOWER SUPPLY PREDICTION*

VANDAN TRIVEDI, IRA MOSCOVICE, RICHARD BASS AND JOHN BROOKS

School of Public Health and Community Medicine, University of Washington, Seattle, Washington 98195

In this paper we develop a semi-Markov formulation for modelling transitions of physicians, nurse practitioners, and physician assistants between different settings and locations within a geographic area. The model predicts the supply of primary care providers over a planning horizon. We then compare the model predictions with estimates of future demand and need for primary care for a community. Statistical tests for validation and sensitivity analysis of the model are also performed to establish the appropriateness of the semi-Markov approach. With the likelihood of an oversupply of physicians during this decade, the model offers a useful tool for health planners, administrators, legislators, and regulators, for objective decision making. (HEALTH CARE PLANNING; SEMI-MARKOV MODELS)

Introduction

This paper presents an analytical model of a primary health care delivery system for a geographic region within the United States. Although we have recently seen an increased emphasis on the delivery of primary health care, there is a serious lack of research in related areas. More research is needed for developing planning, policy-making and control mechanisms for the acceptable delivery of primary care. In this paper, primary health care is defined as the care delivered to patients for their basic medical complaints. It includes the diagnosis and treatment of common illness and disease, preventive services, and uncomplicated minor surgery and emergency care.

The model considers three basic elements of the primary health care delivery system: training of health professionals, delivery of services, and demand/need for primary care within a region. Figure 1 shows the relationship between these three elements. The training component refers to academic training centers for health professionals. These professionals are frequently trained in a large academic health sciences center in a university. There may also be smaller training facilities within the region, such as community colleges which train nursing personnel. Three major types of primary care providers—physicians, nurse practitioners and physician assistants—are considered in this paper. After completing their training, health professionals may locate in the geographic region in which they received their training or move to another region. Similarly, providers trained or practicing in other regions may migrate into the geographic region under consideration. Finally, it should be noted that not all providers deliver primary care; some, for example, various surgical specialists, predominantly deliver nonprimary care, but a small portion of their practices may be in primary care.

Three settings for the delivery of primary care are considered here: private practice (including group- and solo-practice), hospital-based practice, and "other," a category which includes health maintenance organizations (HMO's), county- and state-funded clinics, etc. In addition to the three settings, two locations—urban and rural—are considered.

In this paper, we compare the demand and need for primary care in a geographic region with the supply of providers. The "need" for health services usually implies a
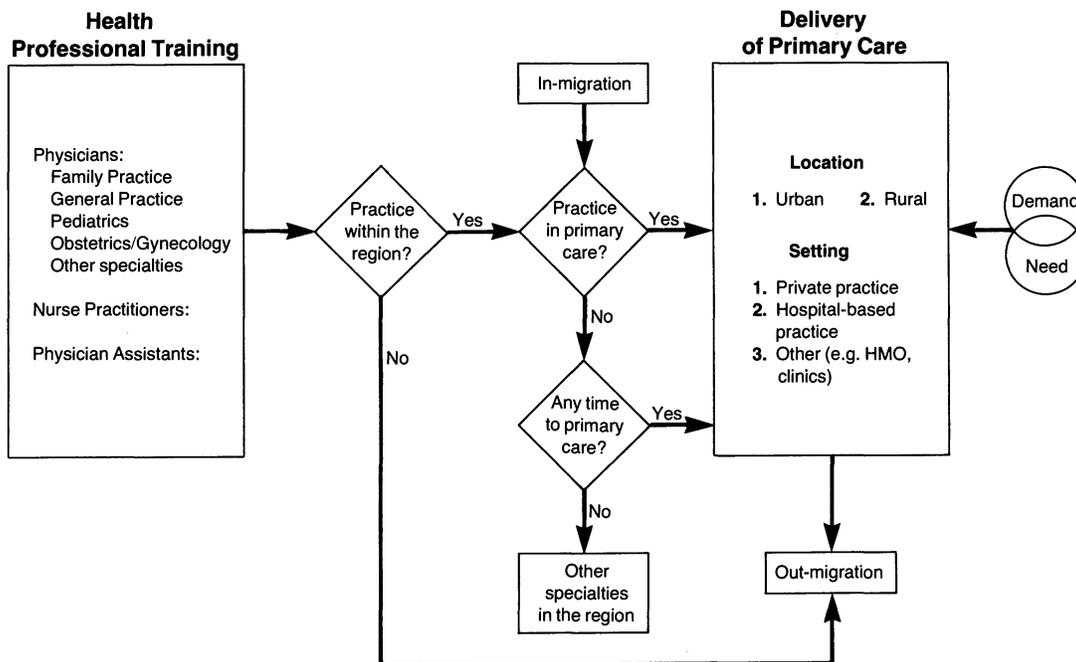
FIGURE 1. Schematic of a Primary Health Care Delivery System.

normative judgment by medical experts on the amount of medical services that should be consumed by individuals to remain or become healthy, whereas "demand" implies behavior, in an economic sense. Utilization is the end result of effective demand and results in visits to health care providers. There are several other components such as the cost of providing primary care, third-party reimbursement, quality of care, and technological changes which affect the delivery of primary health care. However, these components are beyond the scope of the research presented here.

Our model focuses on the stochastic aspects of primary care delivery within a geographic region. We model the transitions of providers between different locations (i.e. urban versus rural) and settings (i.e. private practice versus hospital-based practice). The model is used to predict the supply of primary care providers over a planning horizon and the results of the model are then compared with estimates of demand and need. The model is designed as a decision support tool for those involved with primary health care planning issues. For example, administrators of health science centers, community health planners, legislators and regulators are interested in determining the number and mix of health professionals to train in order to meet the future demand for health services.

Previous Research

Previous operations research efforts have focused primarily on developing optimization models for use in health professional planning. Examples of the use of optimization techniques include the works of Smith et al. (1972, 1976), Shuman et al. (1971), and Schneider and Kilpatrick (1975). Smith et al. developed a mixed integer linear programming model to decide the optimal staff for an ambulatory care practice. They identify the technical opportunities for medical services imposed on the ambulatory care practice. These data are analyzed in an activity analysis model of the practice to identify and assess the implications of efficient patterns of delegation. They recognize the substantial volume of detailed data required by their model and consequently spent a great amount of time developing a strategy for the measurement of the key empirical

constructs on which their analysis must rest. The key to their model is the ability to identify several methods of achieving a given treatment and deciding on the one that makes the best use of scarce manpower sources. For their model to be used for regional manpower planning, additional information is required concerning regional need or demand for health services, as well as the training system's ability to produce additional health professionals.

Shuman et al. formulated a linear programming model to determine the optimal levels of personnel and technology needed to provide health services of acceptable quality at a minimum total cost to the community. Their model is a macro-level model of health professional utilization and allocation within a given region and is developed in several stages including the identification and definition of controllable variables, definition of relevant costs, specification of system constraints, and formulation of an objective function. The controllable variables include personnel and services, level of technology, facilities, and the financial support received by facilities. Unit costs that are considered include direct (e.g., patient fees, cost of developing personnel) and indirect (e.g., cost of not providing needed health services) costs to the community and direct costs to the facility (e.g., support cost, hiring and on-the-job training costs). Model constraints include requirements for services, available personnel, facility capacity, financial concerns, and the quality of the services provided. The model's objective is to minimize the total costs to a community for providing required health services. Of interest is the inclusion in the objective function of direct costs associated with providing services and developing additional personnel and indirect (shortage) costs resulting from not providing needed services.

Shuman et al. view the personnel problem as part of a much larger problem, namely "the determination of an efficient means for the delivery of identified health services to society." Thus, it is their opinion that the supply of personnel and facilities must be looked at simultaneously if there is to be any planning in the health care system. One major problem with the work is that only the analytical framework is presented. Data collection "left for a future study" could be a major obstacle to real world application of the model.

Schneider and Kilpatrick (1975) have developed and validated a set of mixed integer and linear programming models directed at optimal manpower utilization in health maintenance organizations (HMO's). Two basic models, an overall planning model and a subscriber maximization model, treat the interaction between effective personnel utilization, facility requirements, and available capital. The key to the generalization of their model is the direct consideration of the variety of medical teams that can provide medical services thereby "allowing a full exploitation of the structure of the medical care process." Consideration of medical teams also forces the model to incorporate the supervision of nonphysician personnel by physicians. The objective functions of their models incorporate both minimum total cost and minimum feasible use of physicians through the substitution of physician extenders. An important part of the work of Schneider and Kilpatrick is their development of a medical classification system which established transformations between the requirements of the population and the task assignments of the providers. They performed extensive tests to validate the models and also carried out various field trials. These trials were meant to determine the potential use of the models as planning aids for decisions on proper mix of services, staffing patterns, and level of technology in an HMO.

In summary, one can say that there have been several attempts at developing health professional planning models at the regional level and at the level of an individual facility (e.g., HMO, ambulatory care facility). Most of these models either have not been used in the real world or have resulted in unreliable projections. The major emphasis in past research has been on the conceptual development of such models

rather than on the availability of data to make realistic projections (Hansen 1970). Since the actual data needed to test their models either were not available or it would have been too expensive to collect such data, the researchers have used hypothetical data.

The model described here is based on a set of realistic assumptions regarding the primary health care delivery system, and unlike most previous research, incorporates data from readily accessible national and local sources. This is done with the intention of demonstrating the real world usefulness and applicability of the model.

Model Development

The primary health care delivery system within a geographic region is dynamic in that it changes continuously over time; providers move from one location and practice setting to another, they migrate to other regions, and/or new providers enter the system from training programs or from other regions. Our model directly incorporates the stochastic aspects of the health professional training and distribution process. This stochastic element has been lacking from previous health care manpower modeling efforts, although it has been successfully incorporated in a wide array of other manpower modeling efforts in areas such as higher education, manpower, government and the military (Bartholomew 1973 and Stewman 1978).

The model is flexible in that it is generalizable either to a large geographic region (such as a region comprised of several states) or to a smaller area of a few counties within a state. In this paper, the model is applied to the delivery of primary health care in the state of Washington. (Consistent with the demographics of the state, for the purpose of this paper, towns within a ten-mile radius of a city of more than 50,000 population were included in the urban category; all other areas were defined as rural.)

The model assumes that each primary care provider has only one predominant setting available for practice during any one time period. The planning horizon considered for forecasting is a period of eight years from 1982 (base year) through 1990; the time unit considered for change in provider location/setting is one year.

The model assumes that the number and mix of providers at different settings and locations will change over the planning horizon. As mentioned earlier, three settings and two locations are considered for modelling. The frequency with which this change occurs depends on a variety of factors such as in/out migration from the region, the need for different types of services at various settings and locations, the number of individuals trained at academic training facilities, and various socio-behavioral and economic factors.

At any given point in time, the number and mix of primary care providers at a setting/location is random. The main assumption of our model is that the number and mix of providers at a setting/location is given by a semi-Markov stochastic process.

If various settings/locations are assumed to be different states of the stochastic process, then as a provider changes setting/location, he/she can be assumed to move from a state i to some other state, say j. If the transition probabilities are represented by p_{ij}, then p_{ij} indicates the probability that a provider in the ith setting/location will move to the jth setting/location, given that the provider changes states. The value of p_{ii} is assumed to be zero. If there are I setting/location combinations, then in general $\sum_{j=1}^{I} p_{ij}$ < 1 because there is a finite probability that some providers might migrate out of the geographical region under consideration. If the probability of out-migration from a setting i is denoted by $p_{i,I+1}$, then we note that $p_{i,I+1} = 1 - \sum_{j=1}^{I} p_{ij}$.

If p_{oj} represents the proportion of new entrants (including in-migration of providers

from other regions and new graduates from training programs) that enter setting/location j, then $\sum_{j=1}^{I} p_{oj} = 1$.

In this paper we have formulated the probabilities of moving from state i to state j as a semi-Markov process rather than as a Markov chain. The semi-Markov model is selected for several reasons. It is more flexible and general since one does not need to assume that the length of time spent in each state is exponential. Since our data indicated that the time practitioners spent in a given setting/location was not geometric, the greater flexibility available in the semi-Markov model allowed us to incorporate this requirement.

Another advantage of the semi-Markov model relates to the reduction of prediction error. Errors can result essentially from two sources. First, there can be errors due to the estimation of the transition probabilities. The other source of error is inherent in the model since it is a stochastic model. The model not only predicts a point estimate but also the corresponding confidence interval. The width of the confidence interval increases as the number of transitions increase. In a Markov model, for example, there will be eight transitions in an eight-year planning horizon. Judging from our data set, few providers make more than two transitions in an eight-year period. The semi-Markov assumptions allowed us to take advantage of this fact and to greatly reduce the width of the confidence interval, which of course is highly desirable.

The semi-Markov assumption implies that the probability of moving from state i to state j $(i, j = 1, 2, \ldots, I)$ depends only on i and not on the states the provider was in before moving into state i. The probability also does not depend on the length of time the provider has spent in state i or whether the provider has been previously in state j. Further, the semi-Markov assumption implies that the length of time a provider spends in state i may have any distribution, as long as the distribution depends only on state i.

Let us define:

$q_i(t)$ = the conditional probability, given a provider has just moved to state i, that the individual will stay exactly t years in state i before moving again, and

$p_{ij}(t)$ = the conditional probability, given a provider has just moved to state i, that t years later he/she will be in state j.

Then for $i \neq j$,

$p_{ij}(t)$ = probability (from i to j with exactly 1 transition during the period t)
   + probability (from i to j with exactly 2 transitions during the period t)
   + probability (from i to j with exactly 3 transitions during the period t)
   + $\cdots$

$$p_{ij}(t) = \sum_{s<t} p_{ij}q_i(s)(1 - \sum_{r\leq t-s} q_j(r)) + \sum_k \sum_{s<t} \sum_{r<t-s} [p_{ik}q_i(s)p_{kj}q_k(r)(1 - \sum_{u\leq t-s-r} q_j(u))]$$

$$+ \cdots \quad \text{and} \quad (1)$$

$$p_{ii}(t) = 1 - \sum_{i\neq j} p_{ij}(t). \quad (2)$$

Let $N_i(t)$ = number of individuals in state i at time t,

$S_i(t) = E[N_i(t)]$ = expected number of individuals in state i and time t,

$C_{ij}(t) = E[N_i(t)N_j(t)] - E[N_i(t)]E[N_j(t)]$ = covariance $[N_i(t), N_j(t)]$ and

$$\delta_{jl} = 1 \quad \text{if} \quad j = l,$$

$$= 0 \quad \text{if} \quad j \neq l.$$

If we assume that all providers enter the system at time 0, then

$$S_i(t) = \sum_j p_{ji}(t)S_j(0) \quad \text{and} \quad (3)$$

$$C_{jl}(t) = \sum_{i,k} p_{ij}(t)p_{kl}(t)C_{ik}(0) + \sum_i [(\delta_{jl}p_{ij}(t) - p_{ij}(t)p_{il}(t))S_i(0)]. \quad (4)$$

Note that $C_{ii}(t)^{1/2}$ will be the standard deviation of the number of individuals in state i at time t. (Also note that when the model was run for the planning horizon of 1982–90, obviously all providers were not assumed to enter the system in 1982, but adjustments based on actual data were made for how long a provider had been in his/her current state in 1982.)

With the help of equations (3) and (4), we can predict expected values as well as variances and covariances of the number of providers at different settings/locations during a planning horizon from 1982 through 1990.

Data Requirements for the Model

National and local data bases on demand and need for primary care, provider productivity, provider migration rates, as well as population and demographic characteristics for the state of Washington, are required for testing and validation of the model.

Specifically, three major national data sources were utilized to provide a range of estimates for demand and need for primary care visits in the state of Washington: (1) Health Interview Survey (HIS) data from the National Center for Health Statistics (NCHS), (2) National Ambulatory Medical Center Survey (NAMCS) data, and (3) Graduate Medical Education National Advisory Committee (GMENAC) data. HIS and NAMCS data provided two separate estimates of the demand for primary care visits in the state of Washington for the planning horizon of 1982 through 1990.

GMENAC data were used to estimate the need for primary care visits in Washington State from 1982 through 1990. GMENAC was an advisory committee to the Secretary of the Department of Health and Human Services on strategies to achieve an appropriate number of physicians in each specialty in the U.S. The GMENAC data use epidemiologic data in combination with a series of expert panels to develop estimates of health care needs for a breakdown by age and sex of the U.S. population. We applied the GMENAC data to the population in Washington State to estimate the health needs.

In addition to the national data bases, data from several state sources were utilized in the model. They included Cooperative Health Statistics System (CHSS) data on the geographic distribution and attrition rate of physicians by delivery setting. The demographic characteristics of the population in Washington State during the eight-year planning horizon were obtained from the Office of Program Planning and Fiscal Development of the Washington State Department of Social and Health Services. In addition, data on the number of residence slots available in various medical specialties, as well as class sizes for physician assistants and nurse practitioners, were obtained from individual training programs in the region (e.g., the University of Washington School of Medicine) and also from the Washington State Council for Post-Secondary Education.

Since there was no existing data source available for estimating the transition probabilities, a specially designed survey using a stratified random sample of 800 physicians, 150 nurse practitioners, and 150 physician assistants within the state was performed. This sample represents approximately 10% of the population in each category. The response rate on survey questionnaires was 96.9% from physicians, 97.2% from nurse practitioners, and 100% from physician assistants. Along with the estimates of the transition probabilities, this survey also provided additional information on productivity and time allocated by providers to primary care activities.

Tests for Markov Assumptions

Validation and estimation of both Markov and semi-Markov models have been addressed by Shachtman, Schoenfelder, and Hogue (1982) and also by Weiss, Cohen, and Hershey (1982). Several statistical tests were performed on the data to validate its conformity with the underlying semi-Markov assumptions. In each of the following

tests, the degrees of freedom were adjusted as indicated in Shachtman, Schoenfelder, and Hogue (1981). First, a test was performed to see whether the length of time an individual spends in a particular setting/location is dependent on the age of the provider. A standard chi-square test showed that the difference between older and younger providers was highly significant, the younger providers having significantly more transitions than the older providers.

To determine a specific age for differentiating between "younger" and "older" providers, the residual sum of squares were measured as follows:

Let

S_i = time between transitions of providers under age λ,

m = number of providers under age λ,

T_j = time between transitions of providers over age λ,

n = number of providers over age λ,

$\bar{S} = \sum_{i=1}^{m} S_i/m$,

$\bar{T} = \sum_{j=1}^{n} T_j/n$, and

$R = \sum_{i=1}^{m} (S - \bar{S})^2 + \sum_{j=1}^{n} (T - \bar{T})^2$.

Since $\lambda = 45$ minimized R, the residual sum of squares, "younger" providers were defined as those ≤ 45 years of age and "older" providers as those >45 years. As a result of this analysis, two different sets of conditional probabilities, $q_i(t)$'s, were computed: one set for the younger group and another one for the older group.

The next test was performed to validate the semi-Markov assumption. We used the standard chi-square goodness of fit test to see if the waiting times were geometric. We found that for providers in a number of categories the hypothesis of an geometric distribution could be rejected at a 5% level. We therefore concluded that a semi-Markov model would be more appropriate than a Markov model.

To test if the model is of first order and if the process is stationary in time, techniques developed by Anderson and Goodman (1957) were used. Let n_{ijk} be the number of times an individual moves from setting/location i to setting/location j and then to setting/location k.

Let

$$\hat{p}_{ijk} = n_{ijk}/\sum_{l=1}^{m} n_{ijl},$$

$$\hat{p}_{jk} = \sum_{i=1}^{m} n_{ijk}/\sum_{i,l=1}^{m} n_{ijl}, \quad \text{and}$$

$$Q = -2 \sum_{i,j,k=1}^{m} n_{ijk} \log (\hat{p}_{jk}/\hat{p}_{ijk})$$

where m is the total number of settings/locations and Q is the test statistic which is chi-square with $m(m = 1)^2$ degrees of freedom when the hypothesis of first order is true.

The statistic for stationary-in-time test is developed as follows. Let $n_{ij}(t)$ be the number of individuals who are in setting/location i at time $t - 1$ and in j at time t.

Let

$$n_{ij}^* = \sum_{t=1}^{T} n_{ij}(t), \qquad \hat{p}_{ij}(t) = n_{ij}(t)/\sum_{l=1}^{m} n_{il}(t),$$

$$\hat{p}_{ij} = n_{ij}^*/\sum_{l=1}^{m} n_{il}^* \quad \text{and} \quad Q = \sum_{i,j,k=1}^{m} \sum_{t=1}^{T} n_{ik}(t)[\hat{p}_{ij}(t) - \hat{p}_{ij}]^2/\hat{p}_{ij},$$

where T is the number of time increments. Q is the test statistic which is chi-square with $m(m - 1)(T - 1)$ degrees of freedom when the hypothesis of the process being stationary is true.

The first order and stationary process hypotheses were not rejected at the 5% significance level. Thus the data appeared to be consistent with the assumption of a stationary, first-order semi-Markov model.

Estimation of Parameters

We estimated p_{ij} (the conditional probability that if a transition is made from state i, it is made to state j) from the random sample by computing its maximum likelihood estimator as follows:

Let

n_{ij} = number of observed transitions from state i to state j then

$$\hat{p}_{ij} = n_{ij}/\sum_{k \neq i} n_{ik} \quad \text{for} \quad i \neq j,$$

$$\hat{p}_{ii} = 0.$$

The $\hat{p}_{ij}$ values estimated for physicians are presented in Table 1.
Let

m_{it} = number of times individuals entered state i and then moved to another state t years later,

V_i = total number of times individuals entered state i.

We estimated $q_i(t)$ (the conditional probability, given that a provider moves to state i, that the individual will stay exactly t years in state i before moving again) as follows:

$$\hat{q}_i(t) = m_{it}/V_i, \quad t \leq 8,$$

$$\hat{q}_i(9) = 1 - \sum_{t \leq 8} \hat{q}_i(t).$$

Since our planning horizon is up to 1990, $q_i(t)$ for $t > 8$ has no effect on our predictors. So we combined q_{it} for $t > 8$ into one category, which is called $q_i(9)$.

Results

Once the statistical tests on the data were satisfactorily completed and the input parameters were estimated, the semi-Markov model was run for predicting the supply of primary health care services during the planning horizon 1982 to 1990 for the state of Washington. The model was coded in Fortran on a CDC CYBER/7300 computer for interactive runs.

Separate runs were made for physicians (MD's), nurse practitioners (NP's), and physician assistants (PA's). Since 1982 was the base year for the data, the current supply of providers referred to that year. The predictions were available both in terms of the number of health care providers and the number of primary care visits they generated.

TABLE 1

Physician Transition Probabilities

| To Setting/ Location | URBAN | | | RURAL | | | No. Moves Total |
	Private	Hosp.	Other	Private	Hosp.	Other	
F Urban-Private	0.00	0.31	0.38	0.23	0.00	0.08	13
R Urban-Hosp.	0.50	0.00	0.33	0.04	0.04	0.08	24
O Urban-Other	0.79	0.07	0.00	0.09	0.00	0.05	43
M Rural-Private	0.56	0.11	0.11	0.00	0.22	0.00	9
↓ Rural-Hosp	0.17	0.50	0.00	0.17	0.00	0.17	6
Rural-Other	0.44	0.14	0.07	0.36	0.00	0.00	14

The primary care visits were computed by multiplying the number of providers by their productivity. (The productivity was a measure of the annual number of primary care visits per provider.)

The predictions of the supply of physicians by specialty and aggregate settings/locations are presented in Table 2, and the total number of primary care visits generated by MD's, NP's and PA's for the year 1990 as well as demand/need estimates for the population are presented in Table 3.

In addition, we also computed the variances and standard deviations for the productions of providers by using the variance-covariance equation (4). The standard deviations averaged around 2.5% for the year 1990. Thus the 95% confidence interval for the total FTEs of physicians in the year 1990 is 7,357 + 360.5.

Model Validation

Several tests were performed to validate the model and to estimate the relative size of estimation error.

The relative size of error in the model was estimated by a simulation-based sensitivity analysis described below. The predictions generated by the model have two sources of error—the first from the estimates of p_{ij}'s and $q_i(t)$'s (i.e. the estimation errors), and the second due to the stochastic nature of the model. Monte Carlo simulation was used to determine the relative sizes of these two types of errors. The simulaton randomly added or subtracted a fixed percentage (i.e. ±5%, ±10%, and ±20%) to the values of p_{ij}'s and q_{it}'s; each time the predictions generated by the semi-Markov model were evaluated. This process was repeated 100 times. Final evaluation revealed that the predictions were robust against errors in estimating p_{ij}'s and q_{it}'s. The error due to estimation was at most 10% of the error due to the stochastic nature of the model.

The second validation was performed to test the accuracy of the model by comparing its predictions with actual data. To accomplish this, 1980 data were used as the base year data for input to the model. It then predicted physician supply by 1981 and 1982. The model predictions were compared with actual data on physician supply. For example, total number of physicians predicted by the model for 1982 was 5,259 and the actual number of physicians in the state of Washington in 1982 was 5,216—a difference of 43 physicians, or only 0.83%.

TABLE 2

Projections of Physician Supply: 1982–1990 (State of Washington)

Specialty	1982 Base Year	1986	1990
Family Practice	1,269	1,598	1,905
Internal Medicine	625	748	865
Pediatrics	302	371	435
OB/GYN	335	395	454
Non-Primary	2,685	3,215	3,698
TOTAL URBAN	4,207	4,999	5,780
TOTAL RURAL	1,009	1,328	1,577
In Private Practice	4,265	5,291	6,298
In Hospital	534	454	440
Other (HMO, etc.)	417	581	619
TOTAL FTE* PHYSICIANS	5,216	6,327	7,357

* Full-time equivalent.

TABLE 3

Supply Versus Demand/Need Comparisons 1990 *Primary Care Visits* (*State of Washington*)

Location	Age/Sex	Supply	1990 Demand/Need		
			NAMCS (Demand)	HIS (Demand)	GMENAC (Need)
Urban	Male <17	1,362,925	545,365	813,305	1,833,296
	Male ≥17	3,527,522	1,443,313	1,923,263	3,052,762
	Female <17	1,536,927	608,223	736,488	2,070,667
	Female ≥17	5,742,758	2,285,855	3,137,542	4,338,241
	Total Urban	12,170,130	4,882,756	6,610,598	11,294,966
Rural	Male <17	570,271	221,167	329,771	743,445
	Male ≥17	1,650,171	585,127	779,986	1,237,960
	Female <17	660,969	246,758	298,621	839,693
	Female ≥17	2,473,399	926,919	1,272,453	1,759,497
	Total Rural	5,354, 810	1,979,971	2,680,831	4,580,595
TOTAL VISITS*		17,524,940	6,862,727	9,291,429	15,875,561

* Includes visits provided by MD's, NP's, and PA's.

The last validation was designed to test the impact of the semi-Markov property of the model. Since the underlying assumption in the model is that the providers move from setting/location in a semi-Markov fashion, it was of interest to determine the impact of this assumption on the predictions.

This was accomplished by setting the transition probabilities to zero; this would prevent the movement of providers from one setting/location to another. The resulting model predictions were compared with those generated by incorporating the semi-Markov assumption. The comparisons revealed a significant difference between the supply of physicians predicted by the two runs. In particularly, exclusion of the semi-Markov assumption resulted in overestimation of the future supply of primary care providers in rural areas and in hospital-based settings. This is a significant result in light of the fact that there is only a limited mobility among care providers during their careers. This is especially true of physicians since, as supported by the data, they do not move very often. These tests indicated that although there is only a limited mobility among primary care physicians, mobility information reflected in the semi-Markov assumption does improve the accuracy of the forecasts, especially by setting and location.

Sensitivity Analysis

Since the model was coded to run interactively on a computer, it was convenient to perform comprehensive sensitivity analyses on the model. These analyses were designed to respond to several policy issues. These include changes in the proportion of residency slots in primary care specialties (i.e. family practice, general practice, pediatrics, obstetrics and gynecology); changes in the proportion of graduating residents going to rural areas in the coming years; changes in the migration rate of physicians into the state; and changes in physician employment settings.

The results of the sensitivity analysis indicate that changes in the in-migration rate and productivity of physicians have immediate impact on the availability of primary care services, significantly more so than changes in the number and distribution of residency training slots or changes in physician setting/location. This is an important

finding since attempts by policymakers to increase the availability of primary care services have focused basically on manipulating the training environment and providing incentives to attract providers to particular settings/locations. However, our sensitivity analysis indicated that these latter factors had very little impact on the overall future supply of primary care visits for the planning horizon considered in our model.

Discussion

The model presented here provides a better understanding of the stochastic aspects of primary care delivery by examining the changes that occur over time in the provision of primary care services in a given geographic area. The use of the semi-Markov model was preferable to a Markov model because of the greater generality, flexibility, and ability to reduce prediction error. The model validation process indicated that the semi-Markov movement of providers had a significant impact on the prediction of supply of providers. In particular, exclusion of mobility information would result in overestimates of future primary care supply in rural areas and in hospital-based settings.

One can conclude from the model runs that the overall *demand* for primary care will be more than satisfied in Washington State by 1990; this result is independent of urban/rural location. In fact, the *need* for primary care of Washington residents will most likely be satisfied by the projected supply of primary care providers in the state in 1990. However, these findings do not preclude the existence of pockets of primary care underservice in rural or inner city areas in the state. The model predictions shed light on the potential impact of an oversupply of physicians. The increase in the supply of primary care visits between 1982 and 1990 is 62%; this is about three times the rate of increase in primary care demand and need during the period (approximately 20%). The forecasts also indicate a 30% increase in the physician to population ratio (from 1:23 to 1:60 MD/1,000 population) during the period 1982–1990. These estimates are comparable to national increases in physician supply in the 1980's predicted by GMENAC.

This research has indicated that the semi-Markov model offers a valid approach for studying the primary health care delivery system in a geographic region. Rather than relying on hypothetical data, the model incorporates available national and local data sets, making it particularly useful. Since at the present time, comprehensive and reliable data are not available for critical factors such as the costs of health professional training, costs of providing services by settings and locations, and quality of care, these factors were not incorporated in the model. But as more sophisticated data bases become available, the model could be modified to incorporate them. With the definite likelihood of an oversupply of physicians during this decade, health planners and administrators, as well as legislators and regulators, will be increasingly interested in tools for precisely predicting the supply of health professionals that will be available at different settings and locations. This model has been a significant step in that direction.[1]

References

ANDERSON, T. W. AND L. A. GOODMAN, "Statistical Inferences About Markov Chains," *Ann. Math. Statist.*, 28 (1957), 89.

BARTHOLOMEW, D. J., *Stochastic Models for Social Processes*, 2nd ed., John Wiley, New York, 1973.

HANSEN, W., "An Appraisal of Physician Manpower Projections," *Inquiry*, 7 (1970), 102.

SCHNEIDER, D. AND K. KILPATRICK, "An Optimum Manpower Utilization Model for Health Maintenance Organizations,"*Oper. Res.*, 23 (1975), 869.

SHACHTMAN, R. H., J. R. SCHOENFELDER AND C. J. HOGUE, "Using a Stochastic Model to Investigate Time to Absorption Distributions," *Oper. Res.*, 29 (1981), 589.

———, ——— AND ———, "Conditional Rate Derivation in the Presence of Intervening Variables Using a Markov Chain," *Oper. Res.*, 30 (1982), 1070.

SHUMAN, L., J. YOUNG AND E. NADDOR, "Manpower Mix for Health Services—A Prescriptive Regional Planning Model," *Health Services Res.*, 6 (1971), 103.

SMITH, K. ET AL., "An Analysis of the Optimal Use of Inputs in the Production of Medical Services," *J. Human Resources*, 7 (1972), 208.

———, "Analytic Framework and Measurement Strategy for Investigating Optimal Staffing in Medical Practice," *Oper. Res.*, 24 (1976), 815.

STEWMAN, S., "Markov and Renewal Models for Total Manpower System," *OMEGA*, 6 (1978), 341.

WEISS, E. N., M. A. COHEN AND HERSHEY, J. C., "An Interactive Estimation and Validation Procedure for Specification of Semi-Markov Models with Application to Hospital Patient Flow," *Oper. Res.*, 30 (1982), 1082.