Prediction of Dental Care Costs By Use of a Probability Model

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MORE THAN 22 MILLION PEOPLE are enrolled in privately-sponsored prepaid dental care plans. The growth of such plans has been slow because of many deterrents, including the low priority given to dentistry and dental insurance, actuarial uncertainties, and fear of a shortage of dentists.

Most of the growth of dental insurance occurred during the 1960s. In 1960, when three-fourths of the population had hospitalization insurance and two-thirds had some form of coverage for physicians' fees, fewer than one-half of 1 percent had dental coverage *(1)*. Now, current trends indicate that by 1980 between 40 and 75 million people will be covered by some prepaid dental care plan *(2)*.

The Health Maintenance Act of 1973, which mandates preventive dental services as a basic benefit, will undoubtedly boost the already increasing growth of dental care plans. This legislation deals with a special type of prepayment called capitation, which is the amount of money required per person to provide covered services for a specific time. Capitation represents a departure from the traditional fee-for-service reimbursement mechanism, and, in a sense, it is a form of planning and budgeting dental care for a specific population.

The methodology for developing a prepaid capitation rate has been reported by Schoen *(3)*. It is a complex process of adequately researching cost implications of various plans for specific targeted groups and the marketing of those plans.

The process of planning and budgeting, however, must not stop once the rate is negotiated and the plan is accepted by all parties. There is a need for sound management planning to predict the cost implications of subscriber groups demanding dental services. This is especially true if a dental group practice or an HMO is a hybrid organization that contains both prepaid and fee-for-service elements. Without adequate monitoring, it would be impossible to determine if the premiums collected from prepaid patients are appropriate.

Some recent advances in fields fundamental to management planning have been in the quantitative disciplines—mathematics and statistics. Most managers of group practices and HMOs do not have the mathematical background to make some of the calculations required for refined quantitative decision-making techniques. However, managers should be able to understand the quantitative approach well enough to *(a)* state their problems in forms that will enable statistical specialists to analyze quantitative data and *(b)* communicate with those specialists in interpreting the answers obtained by refined methods *(4)*.

In this paper we describe a basic quantitative model that is useful in planning and decision making *(5)* and present an actual application of that model to an existing dental group practice in the Boston area.

Certainty, Risk, Uncertainty

Because a manager is oriented toward the future, he necessarily faces problems with various degrees of uncertainty. In some instances he may assume a condition of certainty. For example, the cost per day of operating a dental unit may change from day to day, but the variability may be so slight that, for practical purposes,

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a manager may assume that the daily cost is known. It may be useful to him to build a model, assuming conditions of certainty that the outcome can be predicted perfectly from the knowledge at hand. Although few situations exist in which a manager possesses perfect information, it is often useful to assume specific values for some variables in order to analyze the effect of other variables.

Problems that a manager faces vary with the existing degree of uncertainty. For many situations he may not have enough information to predict the outcome, but he may be able to determine the chances of different outcomes. Situations in which the manager knows only the probability of the occurrence of the events are called conditions of risk. When the manager possesses neither perfect nor probabilistic information about the occurrence of possible events, such situations are referred to as conditions of uncertainty. This classification tends to oversimplify the numerous degrees of uncertainty, but it is a useful conceptual device for the manager to keep in mind and to orient him toward the concept of probability and its use in planning.

Expected Value

To develop a model that is useful in addressing the problem as stated in the previous section, it is important to introduce the concept of expected value. In general, expectation is defined as: expectation = $P\alpha$, where α is the conditional or dollar value of a particular event and P is the probability of that event and must have the boundaries of $0 \leq P \leq 1$. If there is more than one event of concern, the formula becomes expectation $= P_1\alpha_1 + P_2\alpha_2 + \ldots P_n\alpha_n$ or expectation

$$= \sum_{i=1}^{n} P_i\alpha_i$$

This formula provides the basic mathematical principle. It now becomes the job of the manager to *(a)* define the appropriate events, *(b)* assign a proper dollar value for each event to arrive at a conditional value, and *(c)* empirically derive an appropriate probability weighting for each event.

Schoen *(3)* listed the important cost factors to be considered in discussions of prepaid capitation. He terms one factor initial versus maintenance care. The difference between initial care and maintenance care is significant. Because most populations have a large backlog of unmet needs, initial care takes more time than maintenance care and is of greater cost to the practice. Another factor he describes is age of eligible persons. He states: "Empirically I have noted a sharp distinction between adults and children in dental need, although not much difference between various age groups within the adult and child categories." Schoen's two cost factors can be used by a manager to define four mutually exclusive and collectively exhaustive events that have considerable cost implications.

The following example of computation of expected value represents a stable patient population with only a 20 percent turnover rate or with only 20 percent of the patient load requiring initial year care; it also assumes an equal split between children and adults.

Event	*Probability (P)*		*Conditional value (α)*		*Expected value*
Initial year, adult *(IA)*	.10	x	$150	=	$15
Maintenance year, adult *(MA)*	.40	x	50	=	20
Initial year, child *(IC)*	.10	x	75	=	7.50
Maintenance year, child *(MC)*	.40	x	35	=	14
Total expected value [1]					$56.50

[1] Expected value $= P_{IA}\,\alpha_{IA} + P_{MA}\,\alpha_{MA} + P_{IC}\,\alpha_{IC} + P_{MC}\,\alpha_{MC}$

Thus, the end product of the process is an expected value of $56.50 for each user of dental services. With the appropriate inputs (turnover rate and age distribution) and an appropriate dollar value assigned to each event, a manager can easily determine if the negotiated capitation rate is sufficient to meet expenses. The model presented allows one to judge the cost impact of unforseen alteration of events. By merely deriving different cost projections, using altered probabilities, a manager can systematically develop appropriate contingency plans.

Application to Private Group Practice

Methods. A random sample of 193 patients' records was obtained from a 5-dentist group practice in the Boston area. Although it was a fee-for-service practice, the model used was the same as for a prepaid practice. The intent was to have a preliminary testing of the model, not a detailed analysis of a fee-for-service practice. The sample was drawn from the groups' list of active patients. The treatment experience of each of the 193 patients in their initial year and subsequent years of care or maintenance care was tabulated.

Concurrently with the retrospective survey of patients' records, a 2-month survey was conducted of the average time per type of patient visit. During these 2 months, as charge slips were filled out after each patient visit, the operator also recorded the exact time for each visit. The investigator recorded the number of visits by type and the average time for each. From the average time data and the total overhead and salary costs, the investigator was able to allocate costs to each type of visit. It is important to note that because the dentists were on salary, the allocation process was made easier.

Results. Each patient's treatment history was broken down into seven basic service types. If a patient received more than one service during one visit, this was considered to be two visits for our calculations; these visits represented about 15 percent of all the patient sessions.

The relative costs per visit for adults, ages 18 to 55 and over, and children, 4 to 17 years old, are shown in the following table. The average time per patient visit was broken down by type and age groups. (When the age groups were broken down further, no additional differences were seen in chair time and costs.) For ease of manipulation, we used a relative scale that can be readily converted to a dollar value. Visits for examinations and X-rays are excluded from the following figures because generally patients receive them during their initial visits, and thus these services can be budgeted directly.

Type of visit	*Relative cost value*	
	Adults	*Children*
Operative	5.0	2.61
Prosthetics	8.6	—
Periodontics	5.0	—
Endodontics	5.3	1.74
Oral surgery	3.2	2.53
Preventive	[1] 1	1.02
Orthodontics[2]	—	1.58

[1] After cost allocation, all costs are expressed relative to the cost of $4.50 for a preventive visit for an adult.
[2] Includes only space maintenance and minor tooth movement.

The average number of visits per person obtained when the initial year of care was examined for the 193 patients, broken down into four age groups, are shown in the following table. We derived the conditional values by multiplying the average number of visits by its relative cost value: conditional values equal the sum of the product of average number of visits and its respective relative cost value. An example, for the age group 4-17 years, is:
(CV = (1.2) x (2.61) + (1.0) x (1.74) + (1.1) x (2.53) + (0.7) x (1.02) + (0.3) x (1.58) = 8.8 = $39.60 (8.8 x $4.50)

Type of visit	*Age group (years)*			
	4-17	*18-34*	*35-54*	*55 and over*
Operative	1.2	2.4	2.5	1.2
Prosthetics	0.0	1.0	1.0	4.2
Periodontics	0.0	0.3	1.5	0.1
Endodontics	1.0	1.7	0.4	0.8
Oral surgery	1.1	0.6	1.0	0.3
Preventive	0.7	0.6	0.1	—
Orthodontics	0.3	0.0	0.0	0.0
Conditional values	8.8	34.0	34.0	47.3

Concerning age distribution, the preceding figures indicate that each age group differs in the types of dental visits generated. The conditional values for each age group show a marked dichotomy between children, ages 4–17, and adults, ages 18 and over. In the 55 and over age group, there was a moderate increase in conditional value.

The conditional value results do not contradict Schoen's thesis concerning a child-adult dichotomy because the values presented include the more expensive laboratory costs; in almost every prepaid capitation plan the patient pays a surcharge or some kind of copayment for laboratory work. These laboratory costs, however, did complicate the present application of the model.

It then becomes important to adequately subdivide the event of initial year care-adult into appropriate subevents that will also fit the model previously discussed. The subevents also should be mutually exclusive, collectively exhaustive, and readily derived from a practice's experience. Therefore, we decided that the first treatment session (excluding X-ray and examination) may be an important definition of subevents that has significant cost implications. The classification of subevents was based on three important considerations: *(a)* information required for decision making is readily available from a retrospective survey of dental records, *(b)* a multivariate analysis of dental use by Newman *(6)* has indicated that "presenting dental health status" is the most important predictor of dental care costs, and that initial treatment session is an indication of "presenting dental health status," and *(c)* a predictor should indicate the patients' actual demand for care.

Table 1 presents the event *IA* or initial year-adult broken down into five subevents; the stub of the table designates these subevents according to initial treatment session. For example, subevent "operative" represents those initial year adults whose first visit after examination and X-rays was for operative services. The table also indicates that the patients in the operative subevent generated an average of 2.7 operative, 1.7 prosthetic, 0.1 periodontic, 0.7 endodontic, 0.44 oral surgery, and 0.74 preventive visits. The service mix of the operative subevent has a conditional value of 34.8 or $156.60 when converted to dollars.

In table 1, the subevents based on initial session reveal a wider variation of costs or conditional values than those shown in the preceding text table. No such variation for subgroupings of events was found for the

Table 1. Five subevents based on first treatment session, with their distribution of average number of visit types per adult for initial year of care and respective conditional values

Subevent (initial session)	*Average number of visit types*						*Conditional values*
	Operative	*Prosthetics*	*Periodontics*	*Endodontics*	*Oral surgery*	*Preventive*	
Operative	2.7	1.7	0.1	0.7	0.44	0.74	34.8
Prosthetics	0.4	5.0	0.2	0.4	—	—	48.1
Periodontics	2.3	0.5	4.4	—	—	0.8	38.6
Endodontics	2.6	3.4	0.5	6.4	0.5	1.0	80.7
Oral surgery	2.6	0.8	0.8	—	2.4	0.4	31.3

other three events—maintenance year-adult, initial year-child, and maintenance year-child. The actual values necessary for derivation of expected value for initial year care-adult for the practice surveyed are shown in table 2.

All the relevant groupings of events and their conditional values for the practice surveyed were as follows.

Event	*Conditional value*
Initial year-adult *(IA)*	[1]40.6
Maintenance year-adult *(MA)*	10.9
Initial year-child *(IC)*	8.1
Maintenance year-child *(MC)*	5.3

[1] Derived from expected value $EV_{IA} = \sum_{i=1}^{5} P_i CV_i$ (table 2).

The model is still not complete. The costs of an examination and X-rays have to be added to the projected value. Since all patients should have an examination and X-rays at the initial sessions, the costs for these need not be projected, but they should be budgeted and added to predicted costs.

In summary, a mathematical model such as the one described represents an abstraction of various features of a real situation. Our model, which can be useful for managers of prepaid capitation plans, has the following essential features:

1. A list of four mutually exclusive and collectively exhaustive events *(IA, MA, IC, MC)* that have important cost implications.
2. Assignment of a definite dollar value or conditional value to every possible event.
3. Assignment of a definite probability weight to every event.
4. Each probability weight has a range of $0 \leq P \leq 1$ with the sum of the probabilities of all events being equal to 1.
5. Evaluation of the consequence of certain combinations of events by computation of a weighted average or expected value for the mix of events.

When the model was applied to an actual group practice, it was necessary to:

6. Subdivide event *IA* (initial adult) into subevents based on initial treatment sessions.
7. From subevents, compute expected value for initial year-adult, which in turn was used as a conditional value for event *IA* in calculating expected value for total patient mix.

Discussion

It is appropriate to ask: Is this procedure valid? Validity may be defined in two ways: internal and external. Internal validity of the procedure refers to its accuracy regarding the existing practice configurations. The question then arises as to whether the procedure correctly describes that group and whether it can predict that group's operations beyond the data base on which it was constructed. External validity, on the other hand, is the model's ability to predict the nature of future systems in which the ground rules may change substantially from those of the existing practice, as pointed out in an unpublished paper, "Practical Projection Model for Group Practices," by Dr. G. Kress, Harvard School of Dental Medicine.

Table 2. Expected value *(EV)* of initial year care of adult *(IA)*

Subevents (initial sessions)	*p_i (proportion of sample patients, in percents)*	*CV_i conditional values*
1. Operative	45 (p_1)	34.8 (CV_1)
2. Prosthetics	5 (p_2)	48.1 (CV_2)
3. Periodontics	20 (p_3)	38.6 (CV_3)
4. Endodontics	10 (p_4)	80.7 (CV_4)
5. Oral surgery	20 (p_5)	31.3 (CV_5)

$$EV_{IA} = P_1 \times CV_1 + \ldots p_5 \times CV_5 = 40.6, EV_{IA} = \sum_{i=1}^{5} p_i CV_i$$

To test the internal validity of the developed model, we would have to follow a new cohort of patients in the group practice and determine if the model based on the defined events and subevents would enable accurate projections to be made of the total, types, and costs of services used by the new cohort. External validity is far more difficult to test; however, it could be applied to a group that provides care on a prepaid capitation basis. A prepaid group practice would be sufficiently different from a fee-for-service practice to test the predictive capabilities of the developed model. External validity relates to other generalizable elements of the model.

Is a projection model based on a particular group practice actually limited to the configuration of that group practice? It is fortunate that our sample was not drawn from a specialty group practice, because that kind of practice would strain the external validity of any projections concerning the service demands of a population group. The group practice we studied consisted of four general dentists and a pedodontist who provide comprehensive care; the only specialists they refer patients are orthodontists. We believe, however, that our configuration for the practice we studied would minimize the problem of making generalized projections from highly specialized practice situations.

Again, it is important to note that any changes in the model would require a change or refinement of events, conditional values, and probabilities. The basic, underlying concept of mathematical expectation would remain unchanged.

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