Prediction of Hospital Length of Stay

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Uncertainty in length of patient hospital stay is a major deterrent to effective scheduling for admission of elective patients. Various methods are presented for reducing this uncertainty, including use of diagnostic information, physicians' estimates, and nurses' discharge prediction. It is concluded that physicians' estimates prior to admission, revised by additional estimates after admission, are a useful tool for reducing the uncertainty in length of stay and permitting effective scheduling and manpower allocation.

Introduction

Hospitals are faced with two primary uncertainties in managing facilities and manpower: who will request the patient's admission and how long he will stay if admitted. These uncertainties seriously restrict efficient utilization of manpower and facilities by prohibiting effective scheduling for admission of elective patients, allowing high fluctuations in occupancy and demand for various services. The hospital has no ability to predict future admission requests, but it can reduce the uncertainty concerning the length of stay of its patients. Successful prediction of discharge dates will allow the corresponding scheduling of elective admissions, leading to reduced variance in occupancy and the possibility of either reduced manpower and facilities or higher average occupancy.

Reported here are studies of methods useful in reducing the uncertainty in patient length of stay. Hospital administrators will find that certain combinations of these methods are sufficiently powerful to allow development of effective scheduling systems for elective patients. The methods studied included statistical classification of the patient, physician estimates of forthcoming admissions, physician estimates of discharge date after the patient's admission, and prediction of discharge dates by nurses.

Methodology and Results

Statistical Prediction

The data were taken from the permanent medical record files of Alta Bates Community Hospital, Berkeley, California, and Mount Zion Hospital and Medical Center, San Francisco, California. Data on "all diseases" are from 1961 records of Alta Bates Hospital and 1965 records of Mount Zion Hospital. Data on duodenal ulcer patients are from Alta Bates Hospital for the years 1959 through 1962. These data are based on discharge diagnoses.

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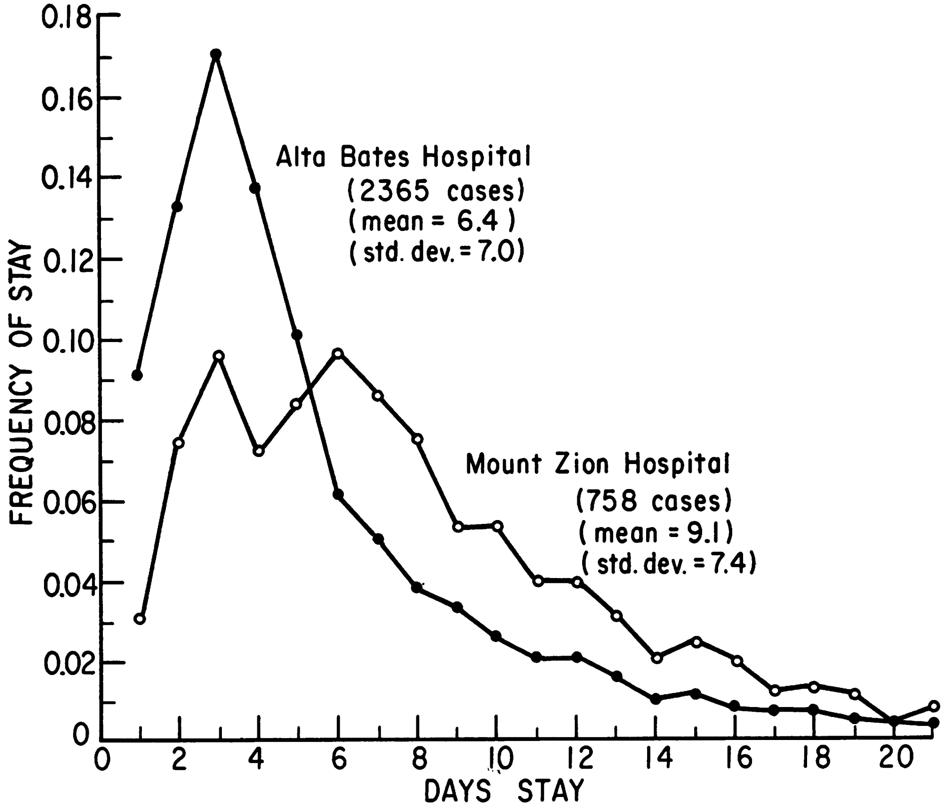

Fig. 1. Frequency distributions of LOS for all patients.

Figure 1 shows the frequency distributions of length of stay (LOS) for patients on medical and surgical services at the two cooperating hospitals. The difference in the distributions reflects Mount Zion Hospital's concentration on more specialized services in a large city contrasted with Alta Bates Hospital's role of serving a suburban area. These distributions can be considered *a priori* knowledge against which the various estimation techniques can be compared, because it is reasonable to assume that any hospital would be familiar with its own LOS distribution. The distributions have the general appearance of the K-Erlang or log-normal density functions; however, no particular purpose is served here by making empirical fits of analytic functions.

Figure 2 shows the frequency distribution for a specific disease (duodenal ulcer) selected as being frequent and having well specified subclassifications. The three distributions shown are: (1) all duodenal ulcer patients at Alta Bates Hospital from 1959 through 1962, (2) a subgroup of patients who had no operation, additional disease, or supplementary complications, and (3) a subgroup that had an operation but without other disease or complications. The

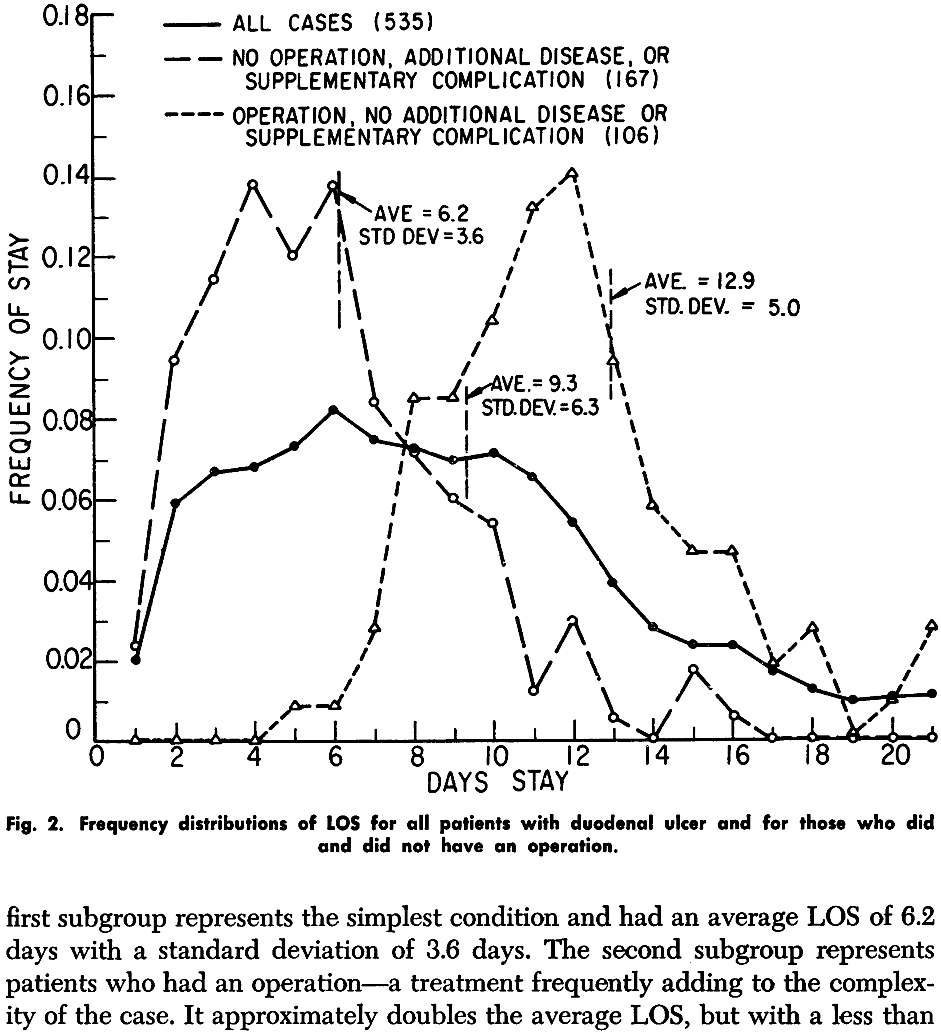

Fig. 2. Frequency distributions of LOS for all patients with duodenal ulcer and for those who did and did not have an operation.

first subgroup represents the simplest condition and had an average LOS of 6.2 days with a standard deviation of 3.6 days. The second subgroup represents patients who had an operation—a treatment frequently adding to the complexity of the case. It approximately doubles the average LOS, but with a less than proportional increase in the standard deviation. The two groups can be further contrasted by noting that by the seventh day, 71 percent of the nonsurgical patients as compared with only about 5 percent of those who were operated upon had been discharged.

The skewed nature of these distributions limits the usefulness of standard deviation to that of a general indicator of uncertainty rather than to a complete descriptor, as would be the case for a normal distribution. It has comparative value, however, since the distributions are of similar form and contain few patients with extreme LOS. Rather than presenting further moments of the distributions, which have little intuitive meaning, it is more informative to compare the frequencies of LOS on days near the modal value, i.e., to examine the most probable discharge days. For example, the general diagnostic specification of duodenal ulcer results in an almost equal probability of approximately 0.07 for discharge on any day from 2 through 12. Additional specification of operation, however, results in the predictability increasing to approximately 0.14 for

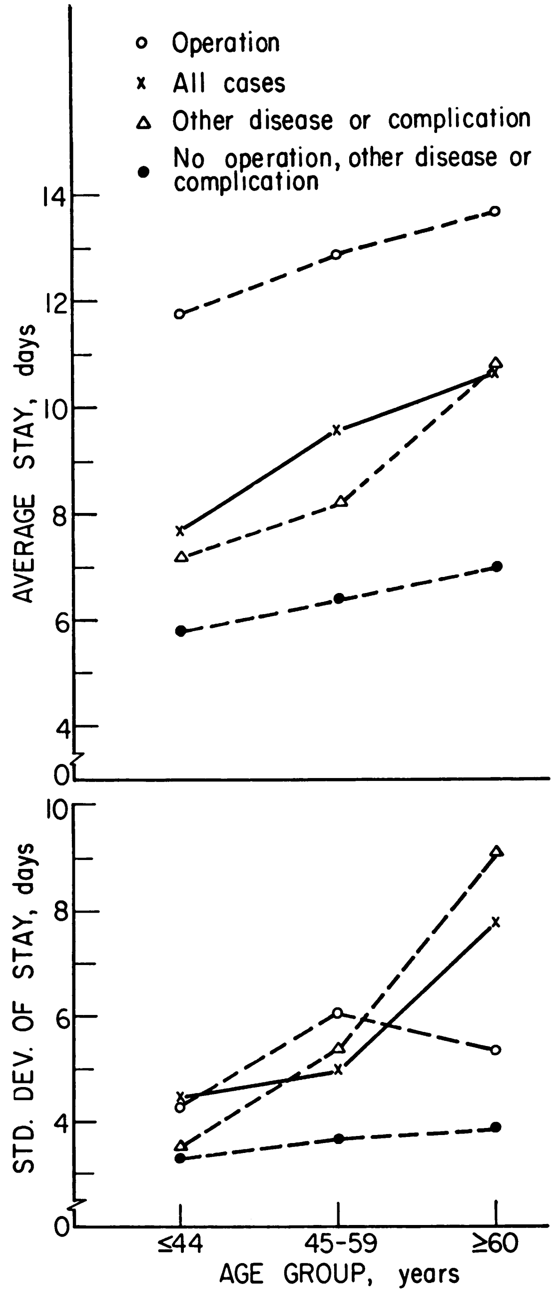

Fig. 3. Average and standard deviation of LOS for various classifications of patients with duodenal ulcer as a function of age group.

days 11 and 12 and being greater than 0.08 for days 8 through 13. Looking at this another way, 65 percent of duodenal ulcer patients would be discharged over a 9-day period, discharge being about equally likely on any particular day. For duodenal ulcer plus operation, 65 percent of the patients would be discharged over a 6-day period with 2 of these days about 1½ times as likely as the others.

Figure 3 shows further analysis of duodenal ulcer cases, introducing patient age as an effective variable along with another subclassification—other disease and complications, or both—in any system. It can be seen that whereas the average LOS is greatest for the operation group, the uncertainty in LOS, as indicated by the standard deviation, is highest for the oldest age group having an additional disease or complication.

Two additional factors investigated were sex and hospital insurance. Female patients tended to stay about one-half day longer, with an increase in standard deviation of one day; insurance appeared to increase the LOS only slightly. Neither of these factors, however, are particularly useful in further delineation of duodenal ulcer cases.

Physician's Prediction of LOS at Time of Admission Request

Forty-six physicians at Mount Zion Hospital estimated the LOS for each of their patients admitted during a six-month period.[1] The physicians supplied estimated LOS to the admissions office when requesting an admission. Actual LOS information was retrieved later from medical records. The participating physicians were volunteers from a group of about 80 selected from both surgical and medical services, contributing from 25 to 270 admissions per year. These physicians gave estimates for almost all of their patients when the system was in complete operation, providing 758 estimates.

Figure 4 shows the average actual LOS and a measure of the uncertainty in actual LOS for five estimate values of 2, 3, 4, 7, and 10 days. The average LOS is indicated by the data points, and the uncertainty, by the vertical lines. Average LOS was the same for both surgical and medical services, whereas the uncertainty in discharge day is larger for patients on medical than on surgical service, particularly for the larger estimates. The uncertainty measure is the range of highest discharge frequency days necessary to include 50 percent of the total discharges. As was noted in the earlier discussion of diagnostic classification, this type of measure is particularly useful with skewed and generally poorly defined distributions. These ranges are more nearly centered on the distribution mode than its mean. For example, patients estimated to stay 7 days on the surgical service had a 50 percent chance of discharge on days 6, 7, or 8; whereas patients with the same 7-day estimate on the medical service had this uncertainty spread over days 5 through 9.

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[1] See [1] for a detailed description of this study.

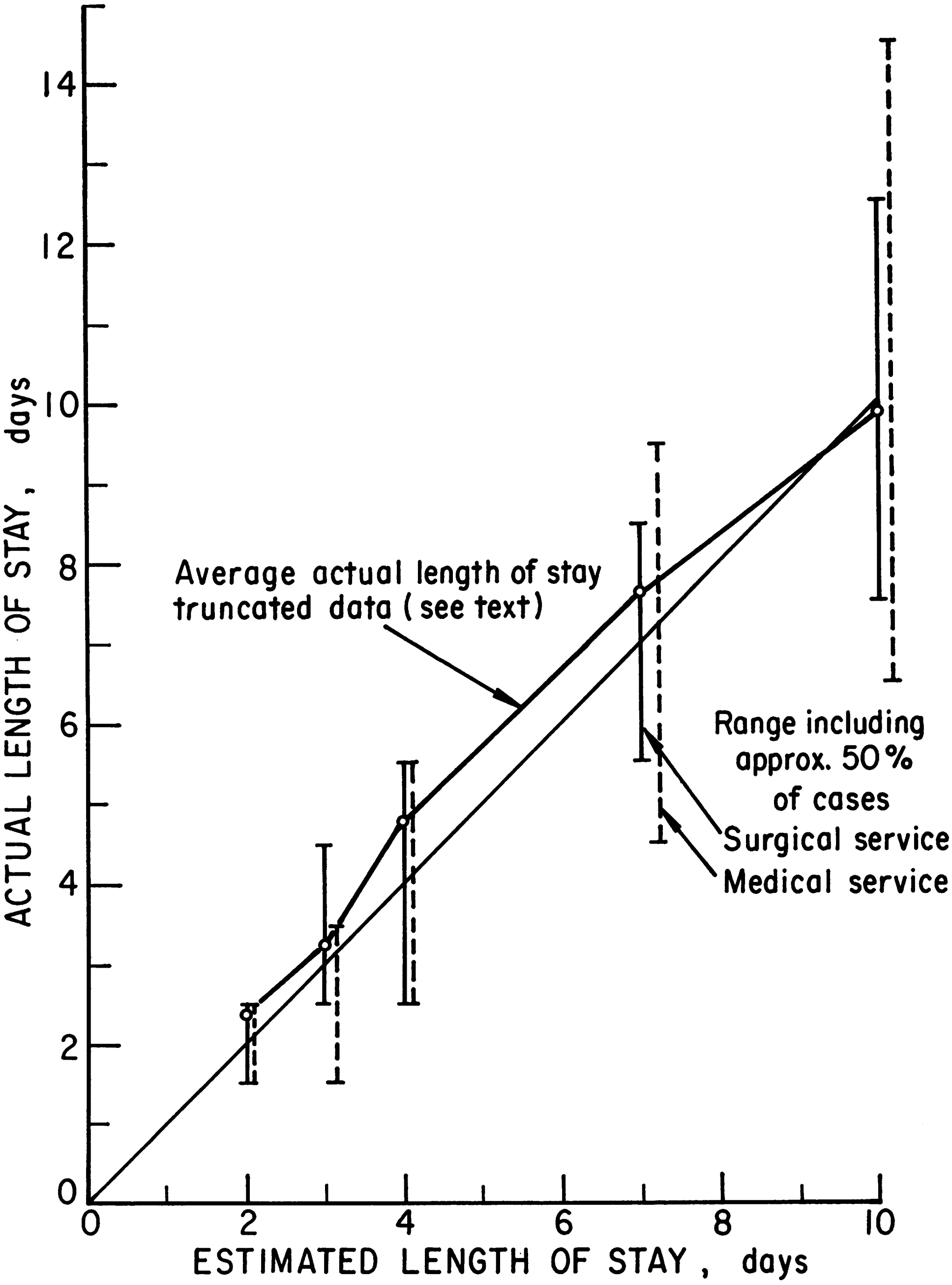

Fig. 4. Average actual LOS and its uncertainty as a function of estimates made by physicians at the time of admission request.

The data are for all patients excluding a group comprising about 14 percent whose actual LOS was more than double the estimate. The inclusion of this small group would add about 2 days to the bias of about one-half day shown in Figure 4 and reduce the uncertainty range interpretation from 50 to 44 percent. Three observations can be made about patients in this poorly estimated group: (1) they incurred additional complications not diagnosed prior to hospitalization, (2) the estimating physician probably did *not* include this pessimistic possibility when producing most of his estimates, and (3) this group was easily identifiable after a few days of hospital stay by gathering a second estimate.

Physician's Prediction of LOS During the Patient's Hospital Stay

The 46 physicians participating in estimations of LOS at the time of admission request also provided a second estimate according to the following schedule:

Original Estimate of LOS, Days	New Estimate Required on Hospital Day
1 - 4	none required
5 - 10	3
11 - 14	5
> 14	7

This estimate was of days remaining, but is converted here to total LOS for comparison with the original estimate. It was made on a form attached to the patient's chart on the appropriate day. Physicians failing to complete the form were contacted later in the day by a hospital employee. A total of 424 estimates were made.

Figure 5 shows actual LOS plotted against estimated LOS, with average values and ranges as described for Figure 4. These data are for both medical and surgical services and represent estimates made on day 3. Estimates made on day 5 appear to offer the same order of predictability. Too few estimates were obtained on day 7 to establish their properties.

The second abscissa labeled *horizon* represents days remaining after the estimate day. The increased precision of this second estimate is evident in comparing the 50 percent ranges in Figures 4 and 5. These data also exclude the patient group whose actual LOS was greater than twice the estimates; but here this group comprises less than 4 percent of the total.

Discharge Prediction by Nurses

In this last study, nurses at Alta Bates Community Hospital listed each day those patients they thought would be discharged the next day, and verified their

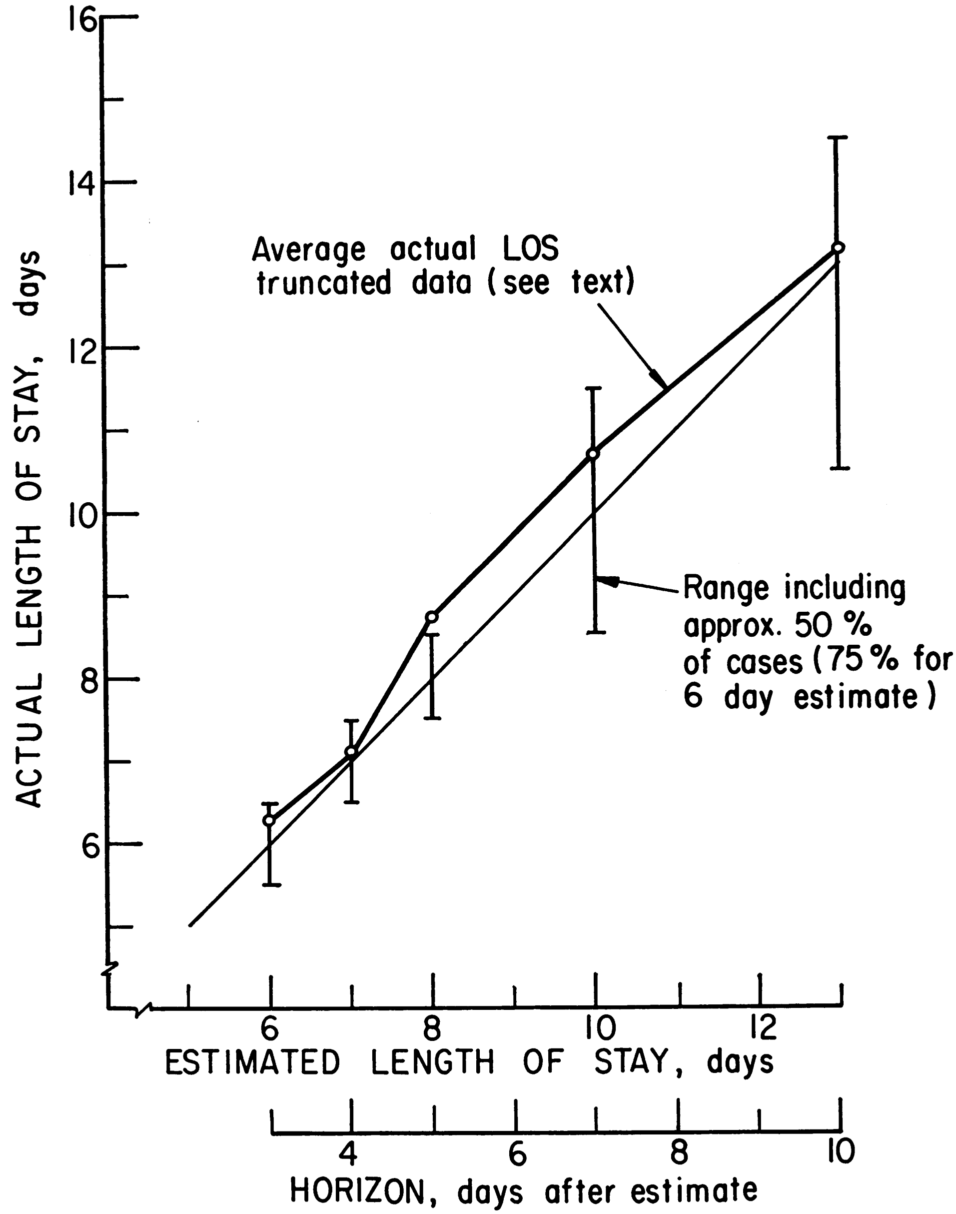

Fig. 5. Average actual LOS and its uncertainty as a function of estimates made by physicians on the third day of patient stay.

estimates with those of the patient's physician. The physicians could agree, disagree and give a new estimate for a listed patient, or add new predicted discharges.

Ward clerks recorded the data, noting when patients actually were dis-

Table 1. PREDICTION OF DISCHARGE ONE DAY IN ADVANCE BY NURSES AND PHYSICIANS

A. Estimates

	No. of Patients	%
1. Nurses' (not verified by physician)	57	10.4
2. Nurses' (agreement with physician)	136	24.9
3. Physicians' additions	42	7.7
4. Physicians disagreed	9	1.6
Subtotal	244	44.6
5. Patients not estimated	300	55.4
Total patients in system	544	100.0

B. Accuracy

	% of Estimated	
	0 days error	0-1 day error
Nurses only (1, 2, 4)	77.7	86.6
Nurses and physicians (1, 2, 3, 4)	81.6	92.6
Physicians only (2, 3, 4)	87.2	94.6

charged and which patients were discharged without prediction. They also reminded nurses to contact the physicians.

Data were collected on two nonmaternity floors for approximately three months. There were no restrictions on patients' age, sex, or disease. Table 1A gives the number and percentage of estimates produced from each of the four estimate sources. Table 1*B* gives the percentages of estimates that were correct and those that were no more than one day in error for the nurses, physicians, and the combined physician-nurse effort. The nurses' accuracy was calculated using estimates from sources 1, 2, and 4, these having been made prior to the physicians' verification. The physicians' accuracy was calculated using estimates from sources 2, 3, and 4, these being either implicit in verifying the nurses' estimates or additions. The combined physician-nurse effort includes all estimate sources, 1 through 4. Unfortunately, estimates were not obtained on a large number of patients. It appeared that many nurses and ward clerks forgot to initiate the procedure, which was new, experimental, and not part of routine duties. Under the assumption that most of these patients were omitted at random, the accuracy figures were computed only for patients on whom estimates were actually made, that is, excluding group 5; the accuracy would be reduced to the extent that omissions may reflect prediction error, the values shown being an upper bound. The inpact of this large number of omitted patients is discussed later in a total system context.

Discussion

Statistical Prediction

The distributions for various subclassifications of patients with duodenal ulcer were taken from the discharge diagnoses as entered in the medical records. Although discharge diagnoses have no predictive value for scheduling purposes, these data were used because the records of admitting diagnoses were at best sketchy and frequently lacked useful diagnostic information. The hospitals in this study made no strong requirement for completeness of diagnoses prior to admission. The question therefore arises as to the relative accuracy and completeness of admission as compared to discharge diagnoses. It is clear, whatever the relationship, that the discharge diagnosis will be more accurate, and the results are therefore an upper bound on predictive ability. Since even the upper bound appears to have, at best, about the same level of predictive power as the direct estimate by the physician, statistical prediction from diagnostic information would seem an unlikely scheduling input. Other investigations of statistical prediction of LOS, using a variety of patient descriptors, have shown a similar lack of precision [2, 3, 4].

Further gains in statistical predictive power can be made by considering more factors, but those gains become increasingly small and probably not economically feasible. Statistical prediction has its greatest utility for long-range planning rather than individual patient scheduling.

Physicians' Estimates

In contrast with a previous report [5], the patient's attending physician appears to be a useful source of predictive information of LOS. Extensive recent research [6] further substantiates this usefulness and delineates how the estimate ought to be produced.

If the initial estimate, made when an admission is requested, is revised at appropriate times during a patient's hospital stay, it should be possible to maintain at least a 50 percent chance of discharge on the day predicted up to about 6 days in advance. For a patient who is estimated to stay longer than 5 or 6 days after the estimate, there is even higher probability that he will occupy a bed for some minimum time. For example, a patient estimated on day 3 to stay 10 days more has better than a 75 percent chance of staying at least 7 days more. The precision of revised estimates shown in Figure 5 is probably relatively independent of the revision day, at least after day 3.

It appears proper to use each new revised estimate as correct, regardless of its deviation from former estimates. A detailed investigation of cases where the revised estimates were substantially greater than the originals indicated that the second, or revised, estimate was more accurate than the original, providing support for the hypothesis that these patients were actually acquiring additional diseases or complications rather than that the earlier estimates were simply inaccurate [1]. In this regard, it appears that the physicians tended to estimate optimistically, that is, although they were aware that a small group of patients would acquire additional diseases or complications, they tended to form their estimates excluding this possibility. This bias imparts additional importance to the use of an early revised estimate to check on a patient's condition immediately after a surgical procedure, intensive treatment, or observation. If the patient continues as originally diagnosed, the initial estimate is relatively unbiased. If, however, he has incurred additional complications, a revised estimate will generally indicate a longer expected stay. The physician's optimistic outlook seems to continue with his revised estimates, and, if a substantial difference in two estimates has been noted, additional revised estimates should be sought.

An Integrated System

The studies reported here were undertaken to develop reasonable means of providing LOS prediction suitable for scheduling the admission of elective patients. The methods evolved from the studies themselves, from empirical evidence, and from the exclusion of methods requiring additional, large-scale research efforts. Reliance on statistical prediction from patient data raises questions in the last category, including the relationship between admitting diagnosis, treatment, and discharge diagnosis. Empirical evidence indicating the large number of potentially important factors effecting LOS, and the large differences in the relative importance of these factors for individual patients led to the investigation of the physician as an estimator; he being the only individual acquainted with both the medical and socioeconomic factors likely to be important.

To minimize cost of data collection, the following guideline is proposed for a predictive system:

The expected stay for as yet unidentified patients can be computed from the distribution for all patients (Figure 1). This is of interest if no information is available on admission, as might be the case in an emergency. It is also useful if the scheduling system is to include possible future admission requests. If a physician requests an admission, either immediately or for a future date, two classes of additional information are potentially available: an admission diagnosis and a physician's estimate of LOS. If the hospital is able to gather statistical data on LOS as a function of the patient's disease, age, projected treatment, and so forth, these data can be used whenever the physician is uncertain about the patient's length of stay or is otherwise unwilling to provide an estimate. Unfortunately, if the physician is uncertain, it is likely that the patient belongs to a class with little statistical data or the precision is poor even with the data. In any event, it is probably the best strategy to accept the physician's estimate as valid, if one is given. This method is particularly advantageous from a cost standpoint, since the time spent by the physician in making an estimate is nominal, considering the high probability that he has already produced one for the patient or his family. If increased diagnostic information were to be required to support a statistical prediction of LOS, it would almost certainly take more of the physician's time. From the hospital's standpoint, the direct estimate has essentially zero cost compared to a computation of an estimate from diagnostic data.

Once the patient is in the hospital, the problem is one of scheduling the dates for obtaining revised estimates. Ideally, estimates should be produced by the physician on his own initiative whenever he feels that his original estimate will need to be altered substantially. This method appears infeasible with present hospital systems because the physician spends a minimum of time with the patient's record and successfully filters out all information but that of immediate interest to him. Expected discharge day would probably be filtered out with the mass of other chart information of no immediate usefulness. If a more efficient physician-hospital communication system were to be devised for communicating orders and prescriptions, for instance, it would be possible to include a question concerning projected discharge day.

Barring a change in the physician-hospital communication system, it probably will be necessary to request estimates at times depending only on the patient's initial estimated stay and possibly contingent on such occurrences as an operation, other well defined treatment, or the results of diagnostic tests. Thus, all patients expected to stay longer than 4 days might be scheduled for a revised estimate on day 2 or 3, but the exact day for this revision could be altered by the nursing staff to reflect each patient's situation. Until further research delineates more completely the estimate revision problem, a useful general rule would be to obtain a new estimate as soon as possible after any extensive treatment or examination. After the first revision, any further revisions could be scheduled for every 5 or 6 days, again adjusting this period if the patient's condition undergoes a substantial change. The responsibility for requesting the revised estimate may be assigned to the nursing personnel and possibly to the ward clerk in concert with one of the attending nurses. It should be emphasized, however, that the date for a revised estimate should only be changed by the nursing personnel, probably advanced in most cases, but that a lack of such action should not preclude the production of a new estimate according to some prearranged schedule.

Each new estimate should be taken as the complete and correct state of knowledge at the time, without any consideration of prior estimates. There are two reasons for this procedure. First, the patient is not a stationary source of random data as required by the usual statistical techniques for combining stochastic data (techniques using Bayesian statistics [7]). Unless the specific nonstationary course of the patient's disease can be assumed, successive estimates cannot be combined. Second, an estimate made more than four or five days after a previous estimate is sufficiently precise to allow the principle of "stable estimation" to apply [7]. This means that the uncertainty in the new estimate is considerably less than in the old, and no particular gain is realized by using both. Fortunately, these two restrictions make it possible to avoid the difficult question of dependence between estimates.

The usefulness of the nurses' prediction of discharge will depend on the frequency with which revisions of physicians' estimates are scheduled. If the nurses monitor the physicians' estimates and suggest changes in revision dates, they can easily sharpen this monitoring within a few days of expected discharge. In view of the physicians' ability to predict within a few days (almost 100 percent correct for 1 to 3 days) it should be possible to predict almost all discharges 1 or 2 days in advance with no error if the nursing station will take the initiative in contacting the physicians.

Utilization of Predicted Length of Stay

The incorporation of LOS prediction into various scheduling systems is now under study using a digital computer simulation of a hospital [8]. Initial results indicate that the inclusion of estimates approaching the precision of those reported here for the initial physician's estimate would allow a hospital to operate about 5 percent higher in average occupancy with the same rejection, rescheduling, or turnaway rates when compared to a scheduling system with no predictive information. The inclusion of revised estimates should allow even a larger gain.

Another hospital operating problem that may be aided by discharge prediction is manpower allocation. It has been noted that nurses, for instance, devote twice as much time to a patient during the first two or three days of his stay as thereafter [9]. If a scheduling system allows for a new patient to be admitted immediately after each discharge, the total number of new arrivals on any single day or within a few days can be predicted three or four days in advance, permitting more effective staff allocation among stations and more effective scheduling of leave and part-time assistance.

The implementation of scheduling and any other systems that require information on future discharges will rely on advanced computation and communication concepts currently being developed for other hospital uses. Once the hospital has committed itself to buy or rent time on an electronic data processing system, for instance, it will only be necessary to provide terminal facilities in the scheduling office and at the nursing stations and to write the appropriate computer programs. The program presented by Wing and Robinson [8] can be adapted to a real-time, on-line scheduling system using estimates of LOS.

The results of these studies generally are indicative of the possible usefulness of LOS prediction. The actual design of scheduling or other systems using LOS information, however, will require further developmental efforts by individual hospitals taking into account their specific patient, physician, nursing, and administrative environments.

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