

## DESIGN OF HOSPITAL ADMISSIONS SCHEDULING SYSTEM USING SIMULATION

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### ABSTRACT

The ultimate objective of the research reported herein is to design an admissions scheduling system which can control hospital occupancy. This paper reports on the initial phase of the research--demonstrating the technical feasibility of developing a simulation model of patient arrivals to and discharges from a hospital, which can be used to design the scheduling system. The specific steps that were accomplished for demonstrating technical feasibility of model development were: (1) develop a hospital simulation model, which can be used for designing the scheduling system; (2) validate the simulation model in two test hospitals; and (3) use the model to design an improved scheduling system which reduces the variability in daily census.

### 1 INTRODUCTION

The control of inpatient bed occupancy has been cited as a source of potentially significant savings in hospitals, without requiring major changes in the structure of medical practice or the method of reimbursement for health care services (Martin, Dahlstrom, and Johnston, 1985; Griffith, Hancock, and Munson, 1973). Specifically, a reduction in the variation of daily occupancy can improve operational efficiency by reducing bed and personnel requirements and improving the utilization of specialized equipment (Redelmeier and Fuchs, 1993). The ultimate objective of the research reported herein is to design an admissions scheduling system which can control hospital occupancy. This paper reports on the initial phase of the research--demonstrating the technical feasibility of developing a simulation model of patient arrivals to and discharges from a hospital, which can be used to design the scheduling system. The specific steps that were accomplished for demonstrating technical feasibility of model development were: (1) develop a hospital simulation model, which can be used for designing the scheduling system; (2) validate the simulation model in two test hospitals; and (3) use the model to design an improved scheduling system which reduces the variability in daily census.

### 2 BACKGROUND

A number of simulation studies have been conducted which have investigated the effects of alternative scheduling systems on hospital performance measures, such as bed occupancy, number of turnaways, cancellations, and patient misplacements. The results from these studies suggest that such performance measures can be improved with alternative scheduling systems. These improved scheduling systems include such features as estimating the length of stay of patients prior to their admission (Robinson, Wing, and Davis; 1968); limiting the number of scheduled admissions (Jeang, 1990); scheduling elective surgery and medicine patients in a more uniform manner throughout the week (Butler, 1992); and instituting a series of scheduling parameters, including number of patients to schedule and number of beds to reserve for emergent admissions, which vary by day of week (Hancock and Walter, 1983; Hancock et al., 1976).

With the exception of Hancock and Walter's Admission Scheduling and Control System (ASCS), none of the recommended systems was ever actually implemented. Hancock and Walter claim that implementation of ASCS saved the eight hospitals in which it was implemented from \$45,000 to \$750,000 per year. The savings in underbedded hospitals were achieved primarily by treating additional patients without incurring a corresponding increase in the costs of staff, equipment, and beds. The savings in overbedded hospitals were achieved by reducing bed capacity without affecting the delivery of services. However, reports on implementation of the ASCS provide only sketchy data to support the claim that predicted and observed improvements in occupancy were actually due to a reduction in census variation, which was the purpose of the scheduling system (Hamilton, Hancock, and Hawley, 1975; Hancock and Walter, 1983; Johnston, Hancock, and Steiger, 1975; Yannitelli and Hancock, 1975). The results from their research indicate that ASCS holds considerable potential for improving the efficiency of the delivery of inpatient care; but additional research is needed to

determine the relationship between the recommended scheduling system, a reduction in census variability, and either an increase in occupancy or reduction in costs. The simulation model discussed in this paper will be used to design a scheduling system like the one described by Hancock and Walter, and to evaluate its effect on census variability.

### 3 MODEL DESCRIPTION

A hospital simulation model was written in the simulation language GPSS/H (Henriksen and Crain, 1993). The model represents patient movement through multiple bed services based on actual patient "flow patterns" identified from each hospital's historical data on patient admissions, discharges, and transfers. Included in these patient flow patterns are admissions to and transfers among medicine (including dermatology and neurology), surgery, medical intensive care unit/coronary care unit (including medical/coronary stepdown unit and telemetry), and surgical intensive care unit (including surgical stepdown unit). The patient flow patterns identified from the two test hospitals were as follows:

#### Hospital A

Medicine  
 Medicine-->CCU/MICU-->Medicine  
 Medicine-->SICU-->Surgery  
 Medicine-->Surgery  
 CCU/MICU  
 CCU/MICU-->Medicine  
 Surgery  
 Surgery-->SICU-->Surgery  
 Surgery-->Medicine  
 SICU-->Surgery  
 Surgery-->SICU

#### Hospital B

Medicine  
 Medicine-->CCU/MICU-->Medicine  
 Medicine-->SICU-->Medicine  
 Medicine-->CCU/MICU  
 CCU/MICU  
 CCU/MICU-->Medicine  
 Surgery  
 Surgery-->SICU-->Surgery  
 Surgery-->CCU/MICU-->Medicine  
 SICU-->Surgery  
 SICU-->Medicine

A small proportion of patients at each site follows more lengthy flow patterns, involving multiple transfers among services. For purposes of model simplification,

these flow patterns have been reduced to one of those listed above; this simplification did not adversely affect model validation.

The distribution of admissions across the possible flow patterns for each admitting bed service is one of the model inputs, and is based on historical workload. The above flow patterns are examples of patterns that patients *should* follow, given bed availability in the appropriate bed services. However, one of the objectives of model development is to investigate the consequences of high average occupancies. Therefore, the model also includes patient flow patterns in the event that a bed is not available in the desired service. That is, secondary patient flow patterns for each site were identified and modeled for patients who cannot follow the primary, or desired, flow patterns because of lack of available beds.

Theoretical input distributions were used for both emergent arrivals and patient length of stay, by major bed service. Use of theoretical rather than empirical distributions for these variables facilitates model implementation because a hospital can use summary data as model input, rather than have to perform a detailed analysis of patient-specific data. Specifically, theoretical distributions require the hospital to simply enter the distribution's parameters (e.g., mean and standard deviation) as model input; while empirical distributions require the hospital to develop a distribution from individual patient records. The exponential distribution was used to model emergency interarrival times, and the lognormal distribution was used for modeling length of stay. Both of these distributions have been used extensively in previous simulation studies of health care systems.

### 4 DESCRIPTION OF SCHEDULING SYSTEM TO BE MODELED

Once the simulation model is developed and validated for a given hospital, it can be used to design the scheduling system, which consists of various scheduling parameters and decision rules. The scheduling system is incorporated into the simulation model, then combinations of different values of the parameters are systematically tried as model input, along with the hospital's historic or projected values for the other input variables. Model output includes predicted values of hospital performance, which will be reviewed by hospital clinical and administrative staff. The values of the scheduling parameters which result in a desirable combination of values for daily census, overall occupancy, cancellations, and turnaways become the parameters of the scheduling system to be implemented in the hospital. If the hospital decides to implement the recommended scheduling system, it will consist of a

simple software program which performs a series of calculations using the parameter values plus daily data on bed availability. The results from the calculations will be used by admitting personnel in their daily admitting and scheduling decisions.

The admitting decisions that must be made each day include the following:

- 1) How many elective admissions should be scheduled, by bed service, by day of the week?
- 2) Given current bed availability at a given point on a particular day of the week, how many patients (if any) should be called in?
- 3) Given current bed availability at a given point on a particular day of the week, how many scheduled admissions (if any) should be canceled (to ensure bed availability for emergency patients)?

The answers to the above questions ultimately determine a hospital's overall occupancy, as well as the number of cancellations and turnaways incurred.

A computer-based scheduling system should perform the required calculations to provide the answers to the above questions. To perform these calculations, the scheduling system requires data on current bed availability (for questions 2 and 3), as well as values of the scheduling parameters, which are day-of-the-week specific.

The scheduling parameters required for responding to question 1 are the day-of-the-week numbers of scheduled appointment slots. No further calculations based on current bed availability are required. For question 2, the research by Hancock and Walter has shown that two decision numbers should be determined: a "call-in allowance" (CIA), and a "call-in maximum" (CIM). Using these numbers, the answer to question 2 is calculated as follows: If the current number of empty beds  $>$  CIA, then the number of patients to be called in = empty beds - CIA, but should not exceed CIM. The call-in allowance is used to determine if the number of empty beds is sufficiently large that additional patients can be called in without adversely affecting bed availability for scheduled admissions later in the week. If enough beds are available that patients can be called in, then the call-in maximum sets a limit on the number of patients that can be called in, so that the distribution of discharges (and hence, daily census) is not adversely affected.

Finally, question 3 requires a value for the number of empty beds that must be reserved for emergency patients, or the "emergency reserve allowance" (ERA). The answer to question 3 is calculated as follows: If  $ERA >$  the number of empty beds expected after all scheduled patients have been admitted, then the number of scheduled patients to cancel is  $ERA - \text{empty beds}$ .

In summary then, the values of 28 different scheduling parameters must be determined for each bed service which falls under the guidelines of the proposed scheduling system: four decision numbers for each of the seven days of the week. The four decision numbers are (1) number of elective patients to schedule; (2) call-in allowance; (3) call-in maximum; and (4) emergency reserve allowance. The purpose of the simulation model is to help determine the values of the 28 scheduling parameters.

## 5 RESULTS

The simulation model that will be used for designing the scheduling system must be (1) easily applied to multiple hospitals; (2) valid--i.e., an accurate representation of the actual system being studied; and (3) able to demonstrate a reduction in census variability with a change in the scheduling system. The achievement of these criteria is discussed below.

### 5.1 Ease of Application to Multiple Hospitals

The model is easily customized for a given hospital by making changes to definitions of the following input variables:

- Number of major bed sections
- Number of beds in each section
- Average and standard deviation of patient length of stay in each section
- Arrival rates of emergency patients, by day of week
- Distribution of emergent admits, by treating specialty and patient flow pattern
- Distribution of elective admits, by treating specialty and patient flow pattern
- Identification of first and second alternative bed sections (used when all beds in desired section are full), by bed section

To apply the model to a new hospital, the hospital characteristics listed above are determined, and changes are made to the corresponding definitions, tables, or matrices in the model "definitions" section. These changes consist of simply editing numbers or unit identifiers. No changes need to be made to any of the program code describing patient movement. Thus, the model was easily customized to represent the two test sites included the research.

### 5.2 Validation

The validity of a simulation model is established by comparing model and system behavior. The methodology used in this research for performing the comparison was a graphical approach, which is the most commonly used method for the validation of

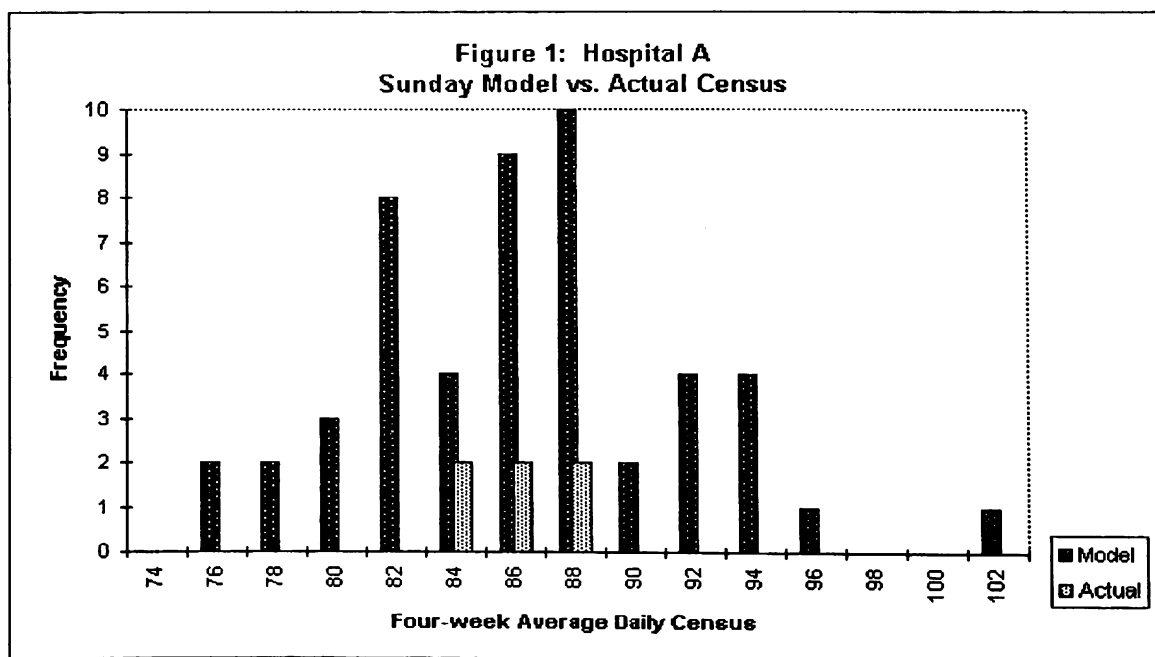
simulation models (Sargent, 1994). Confidence intervals and hypothesis tests are also used, but less frequently. A graphical methodology, rather than hypothesis testing, was used for evaluating the validity of the admissions scheduling model because observations of daily census are autocorrelated, and because limited data are available from the actual system. When observations are autocorrelated, classical statistical tests based on identically and independently distributed observations are not directly applicable. Furthermore, because a simulation model is only an approximation of the actual system, the null hypothesis that model behavior and system behavior are the same will almost certainly be false (Law and Kelton, 1991, p. 312). While formal statistical tests may lead to the conclusion that a model is not valid, it may still be valid for the purpose for which it is intended. This is especially true for models that are designed primarily for comparing alternatives than for predicting absolute answers, as is the admissions scheduling model.

To compare system and model behavior, actual census data were obtained from the two test hospitals for a six-month time period. A six-month time period was selected because it is expected that this would be the amount of time for which the scheduling parameters would be set. (Every six months the performance of the system and the assumptions underlying the model would be evaluated and the parameters reset, if necessary.) Because the parameters are set by day of week, it is important that the model accurately predict census by day of week; hence, actual census by day of week was compared against model census by day of

week. Furthermore, because of the potential problem of autocorrelation of census figures (even though the observations for a given day of the week are separated by six-day intervals), the average daily census for a four-week time period was used as the performance measure for comparison.

During a six month time period (26 weeks), six observations of the four-week average daily census (ADC) were available for each day of the week from both medical centers. These observations constitute the "actual" data. The distribution of these observations was compared with the distribution of 50 observations of four-week ADC data from the model. Any number of observations can be generated from the model; 50 was selected because it appears (from the graphs) to be a sufficient number for depicting the general shape of the distribution. A valid model should produce a distribution of observations that encompasses the observations from the actual system. Since the four-week ADC is a random variable, the six observations of actual data represent a sample from a distribution, which we want the model to be able to reproduce. Figure 1 is an example of the model and actual distribution of four-week average daily census by day of week for Sunday at one of the test sites. Similar results were obtained for all days of the week, for both test sites, demonstrating that the samples of actual data fall well within the distributions from the model.

In addition to seeing that the distribution of actual observations falls within the model's distribution of observations, we want to see that the system's mean census is close to that of the model's mean census.



Therefore, we compared the mean from the sample of hospital observations with the model's "population" mean--i.e., the mean of the 50 four-week observations generated by the model. Table 1 shows the difference between model and actual means for all days of the week for hospital A. The difference ranges from 0.1 to 1.7. These differences are within the acceptable range established by the Chiefs of Medicine and Surgery at the test site, who stated that a credible model should predict within two beds of the actual census. Table 2 displays the differences for hospital B, all of which are also less than two beds. Based on these results and the graphical comparisons, the model is considered valid. The validation methodology and results are also discussed by Sargent elsewhere in these *Proceedings* (see "Some Subjective Validation Methods Using Graphical Displays").

Table 1: Difference between Model and Actual Mean Daily Census, Hospital A

	Model Mean <sup>1</sup>	Actual Mean <sup>2</sup>	Difference
Sun	85.4	85.3	+0.1
Mon	95.6	95.5	+0.1
Tues	98.9	98.1	+0.8
Weds	98.4	98.2	+0.2
Thurs	98.5	96.8	+1.7
Fri	84.7	83.8	+0.9
Sat	78.1	78.0	+0.1

<sup>1</sup>Based on 50 4-week observations.

<sup>2</sup>Based on six 4-week observations.

Table 2: Difference between Model and Actual Mean Daily Census, Hospital B

	Model Mean <sup>1</sup>	Actual Mean <sup>2</sup>	Difference
Sun	48.1	47.9	+0.2
Mon	55.8	56.3	-0.5
Tues	58.0	57.9	+0.1
Weds	60.5	60.3	+0.2
Thurs	61.6	61.9	-0.3
Fri	53.1	53.4	-0.3
Sat	46.9	47.2	-0.3

<sup>1</sup>Based on 50 4-week observations.

<sup>2</sup>Based on six 4-week observations.

### 5.3 Reduction in Census Variability with New Scheduling System

As indicated above, the purpose of the admissions scheduling model is to identify a set of scheduling

parameters which results in a decrease in census variation from the current system. Therefore, if the simulation model is to be used for this purpose, it must be able to show a reduction in the variation in daily census between the current scheduling system and the proposed, improved scheduling system. For example, figure 2 presents a "box and whisker" plot of the variation in daily census at Hospital A for Wednesdays. The figure presents the results for five model replications of one year each (52 observations) under the current system, and five replications under the new scheduling system (i.e., one set of values of the scheduling parameters). The plots for all days of the week showed a modest, but observable, reduction in census variation under the new scheduling system for Mondays through Thursdays. The new scheduling system is most likely to affect these days of the week, because the majority of admissions on these days are scheduled and can be controlled. Additional experimentation with the simulation model to investigate the effects of other values of the scheduling parameters on census variability is currently being conducted.

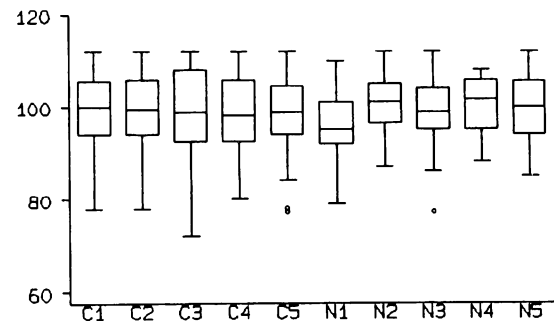


Figure 2: Current vs. New Scheduling System Wednesday Replications 1-5

## 6 CONCLUSION

The results from this research demonstrate the feasibility of developing a valid simulation model of patient arrivals to and discharges from a hospital, which can be used for evaluating the effects of alternative scheduling systems on census variability. The model is easily customized to multiple hospitals, is valid, and can demonstrate a reduction in census variability from modification of values of the scheduling parameters. Work is proceeding on using the model to design scheduling systems for the two test hospitals.

The hospital simulation model offers other benefits besides the design of an improved scheduling system. For example, it can be used for determining the appropriate allocation of beds between different

specialties and subspecialties. One of the test sites, as well as the Michigan Voluntary Hospital Association, have expressed interest in using the model for this purpose. The simulation model also provides a mechanism for structuring the hospital's planning process. By requiring hospital clinical and administrative staff to project inpatient workload and case-mix, and to define these projections in the precise terms required for the model's input variables, the model facilitates the discussion and definition of assumptions necessary for the planning process. In addition, the knowledge gained about the admissions process while designing and validating the simulation model may prove to be invaluable to helping the clinical and administrative staff understand how the current system really works, as opposed to how everyone thinks it operates (Shannon, 1992, p. 66). In turn, the process of designing and validating the model may be of great value toward suggesting improvements in current procedures (Banks and Carson, 1984, p. 4), even if the proposed scheduling system is never implemented.

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