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DYNAMIC SIMULATION MODELING OF ICU BED AVAILABILITY

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ABSTRACT

The intensive care unit accounts for nearly 30% of all inpatient expenditures while representing only 8% of the patient population. All healthcare systems must balance the need for access and availability of intensive care unit beds (ICU) versus excess capacity that wastes increasingly limited healthcare resources including bed space and personnel. The Cincinnati VA Medical Center is an acute care, university affiliated 220-bed facility serving eligible veterans with medical, surgical, neurological and psychiatric care needs. ICU beds are unavailable nearly one third of the time, eliminating new ICU admissions, and requiring diversion of ambulance traffic. Diverting ambulance traffic adversely impacts patient satisfaction and community perception of quality of care delivered at this center. Phased construction to relieve the problem was planned, including additional telemetry beds, move of ventilator dependent patients out of the ICU to a Respiratory Care Unit (Tele/RCU), and development of ICU swing beds in the emergency room area (Heart ER). We assessed the likelihood that the planned changes would result in the desired outcomes.

A computer model representing medical bed utilization at this facility was developed using dynamic simulation software (Arena®). This model analyzed the flow of patients through the ICU, telemetry and medical floor beds under current bed allocation. The model was then used to evaluate the effects of the planned phased construction. The model demonstrated improved availability of ICU beds with the addition of the telemetry and respiratory care unit beds. Resolving ICU access problems required addition of Heart ER beds. Unexpectedly, increased ICU bed availability resulted in increased telemetry and medical floor bed utilization downstream and increased length of stay on the medical service as the proportion of post-ICU patients increased on the floors.

1 INTRODUCTION

The Cincinnati VA Medical Center serves the veteran population in southwest Ohio and neighboring areas of Indiana and northern Kentucky. A broad range of inpatient and outpatient services are provided. Medical and neurology patients utilize 70 floor beds, 15 telemetry beds and a small, 10 bed mixed Medical/Cardiac ICU.

Access to ICU beds is a critical problem for this facility. Medical ICU admissions doubled in the last decade as the medical center became a referral center for other nearby outpatient and inpatient VA facilities. Systems changed to maximize utilization of valuable ICU resources included changing the model of medical care, designation of a patient expediter for early identification of bed logjams, development of an algorithm for telemetry utilization, and designation of ICU chiefs as final arbiter of bed availability. These adjustments initially improved ICU bed availability. As growth continued, however, no ICU beds are available during the busiest winter months approximately 30% of the time. When this occurs, ambulance traffic is diverted to nearby facilities that often are also near capacity. This presents a hardship to the patients who routinely receive their care at this center. It also creates a perception of insufficient planning for the delivery of quality medical care. With these issues in mind, renovation and construction plans were developed to improve the availability ICU beds at this hospital. Resources are limited, so it is important to consider the most efficient distribution of any added beds.

As part of a strategic planning initiative, a multi-disciplinary group identified critical elements for admission to the ICU and for delays in discharge from the ICU. Members brainstormed potential redesign of care to improve ICU access. The number of daily admissions and timing of ICU admissions and discharges, the distribution of cardiac and medical diagnoses, and the lengths of stay for the ICU were collected over a one-year period. The

number of medical telemetry and floor admissions and lengths of stay were also recorded for this period. Average, minimum and maximum daily emergency room admission rates were determined. The rates of transfer between the ICU, telemetry and floor beds were estimated. The time delays in transfers between units, including time to write the orders, call report, clean the bed, and transport the patient had been determined by a separate workgroup at this center. The mortality rate for the patients in the different settings was collected over the same one-year period. This information was used to develop the computer model. Arena dynamic simulation software was used as this allowed us to analyze this system with multiple probabilistic inputs.

2 MEDICAL BED MODEL

2.1 Original Bed Configuration

Medical beds were divided between the ICU, telemetry unit, and the general medical floor. Admissions come from the outpatient area; the emergency room, the clinics and from outlying facilities. Patients could be transferred between any of the medical units as indicated by their condition.

2.2 Model Inputs and Assumptions

The physical entities for this model were patients admitted with medical or neurological illnesses. The basic time unit for the simulation was one hour. The model was run for 40 days. Results from the first 10 days were discarded to allow the hospital to fill and reach a fairly stable state. Review of the plots confirmed that this was appropriate. Twenty repetitions were made of each version of the model. This produced adequate 95% confidence intervals for the measures of greatest interest.

There are over 900 admissions to the ICU each year. Of these, 80% come from the outpatient arena (OPC and Emergency Department) and the other 20% are transferred from the floor or telemetry beds. Based on the nature of the admissions process and the available data, an exponential distribution was chosen to represent arrival rates for each of the three medical units. The mean arrival times were estimated from the available data. The means were 15, 7, and 3.6 hours for the ICU, Telemetry, and Floor arrivals, respectively. The average length of stay (LOS) in the ICU is 71 hours, just short of three days. The range of length of stay varied from 18 hours for those patients with "rule-out myocardial infarction" to 9 days for patients with multi-organ system failure and/or ventilator dependence was chosen after discussion with ICU personnel. The average LOS on telemetry averaged 36 hours, ranging from 18 hours to 5 days. A triangle distribution was used for the LOS in both the telemetry and the intensive care units. The average LOS for the floor beds is 6 days and was assumed to be normally distributed with a standard deviation of 1.5 days.

Bed down time, when a bed was not available for occupancy while dirty linens were stripped, the bed and room cleaned, and the bed remade, was described by an exponential function with a mean of 3 hours plus an additional .5 hours. Movement within the facility from one level of care to another accounts for a significant portion of bed utilization. Based on one year's data, 55% of ICU patients go to telemetry beds, 40% are transferred to floor beds, and 5% are directly discharged. In the telemetry unit, 50% of patients are discharged from the unit, 40% are transferred to a ward unit, and 10% transferred to the ICU. Of the medicine floor patients, 80% are discharged from the facility, 11% move to telemetry, and 9% are transferred to the ICU.

2.2 Alternative Bed Configurations

The first alternative evaluated was the addition of nine total telemetry beds, for a total of 24 available telemetry beds. These include a Respiratory Care Unit capable of handling patients on ventilators who were otherwise stable. This would be expected to decrease the maximum LOS in the ICU to 8 days. Additionally, the average LOS in the ICU would be expected to decrease to 69 hours as an estimated 10% of the patients, with the longest LOS, are transferred to the RCU beds. The additional ventilator-dependent patients are expected to increase the average LOS in telemetry to 48 hours, with the maximum being 10 days. A triangle distribution is expected to still be the most appropriate expression for the LOS on these two units. We assumed the additional telemetry beds would have little impact on the LOS of patients in the medical floor beds.

The third version of the model describes this facility after the remodeling of the emergency room with the addition of 3 Heart ER beds. This adds capacity with swing beds in the emergency room for critically ill patients, including some of the admissions to rule out myocardial infarction. If half of this latter group are cared for in the Heart ER instead of in the ICU, the average LOS for all ICU beds is expected to decrease to 66 hours. The addition of the Heart ER beds is not expected to significantly impact the LOS in the other medical bed locations.

2.3 Modeling Issues

This simulation model was used to analyze the flow of patients through the medical beds at this center. It was used to model the current bed situation as well as two alternative configurations as planned in phased construction. The major concern was to evaluate the

effects of the planned changes on access to the ICU. Other issues evaluated included:

- The number of patients discharged per month
- Utilization of ICU beds and LOS
- Utilization of telemetry beds
- Utilization of medicine floor beds
- Impact on overall LOS of medical patients
- Validation of the model using current bed configuration results compared to data collected over one year

2.4 Model Findings

Using the existing bed configuration, the ICU was full (defined as all available beds occupied and two patients waiting to be transferred) on average 25.7% of each month. This compares well with data collected over the past 4 years. The model showed that 23 patients were diverted to other facilities each month. The actual number is not available, but this follows logically from the admission rates and the amount of time that the ICU is full. Average ICU bed utilization is 92.6% (maximum 100% utilization). Telemetry bed utilization is 91.3% (maximum 100% utilization), but floor beds are in use 81.2% of the time (maximum utilization 97.7%). Average LOS on the medicine service is 7.4 days (see table 1). This is slightly longer than the 1998 average LOS of 6.9 days. The number of discharges per month compares well to the 1998 average of 322.3 patients per month.

Adding telemetry and RCU beds decreases the period of time that ambulances are diverted to 19.4%. On average, 17.2 patients are still sent to other facilities each month. Average utilization is 88.6% for the ICU and 88% for the telemetry beds. Average floor bed utilization is stable, while average maximum use increases slightly. Average overall LOS increases to 7.9 days.

Table 1: Impact of Planned Changes on Access to the ICU

Configuration / Measure	Present Ave. (half width)	Add Tele/RCU Ave. (half width)	Add Heart ER Ave. (half width)
ICU beds ave utilization	**92.6% (1.5%)**	**88.6% (2.9%)**	**81.0% (2.7%)**
ICU beds ave max utilization	**100%**	**100%**	**100%**
Telemetry beds ave utilization	**91.3% (2.3%)**	**88.0% (3.2%)**	**92.9% (2.8%)**
Telemetry beds ave max utilization	**100%**	**100%**	**100%**
Floor beds ave utilization	**81.2% (2.2%)**	**81.7% (2.2%)**	**84.5% (2.5%)**
Floor beds ave max utilization	**97.7% (1.6%)**	**98.9% (1.2%)**	**98.6% (1.8%)**
ICU Wave-off #	**23.0(4.5)**	**17.2 (4.0)**	**5.8 (2.1)**
ICU Wave-off Time %	**25.7 (3.9)**	**19.4 (3.4)**	**6.4 (2.2)**
Average LOS (days)	**7.4 (.12)**	**7.9 (.13)**	**8.1 (.16)**
Discharges	**316.3 (6.9)**	**311.8 (5.3)**	**322.9 (8.1)**

Completion of the planned construction, including the Heart ER beds, reduces the time the ICU is full to 5.8%, with approximately 6 patients diverted in an average month. Average ICU utilization drops, but maximum utilization remains 100%. Occupancy rates of the telemetry beds remain high. Average floor bed use increases slightly while maximum use is stable. Average LOS increases to 8.1 days. The number of discharges increased in the final configuration, reflecting the decrease in the number of critically ill patients diverted to other hospitals each month.

3 CONCLUSIONS AND RECOMMENDATIONS

The Medical ICU has very high utilization rates. The model predicts average ICU utilization rate of 81% when a respiratory care unit is created for long-term, ventilator-dependent patients and ICU swing capacity is added with the addition of 3 Heart ER beds. We created a model to assess ICU bed availability while controlling costs by using alternative approaches to meet patient needs outside of an ICU setting. Modeling allowed forecasting of the extent to which the aims of the renovation would be met and identification of unexpected consequences. In areas of

uncertainty, input variables were changed to determine the degree to which the process was influenced by each variable.

Unfortunately, the model predicts sustained high levels of telemetry and floor utilization, even with the increase in available telemetry beds. Telemetry bed utilization may be expected to remain high due to the backlog of patients waiting to get into a telemetry bed under the current bed configuration. We have greater control over this queue of patients. Unlike a server in a manufacturing plant, we are capable of deciding that a patient no longer needs to go to, or stay in, the telemetry unit. Although our model kept floor beds stable, design considerations in the renovation project have resulted in a 20% loss of floor beds. Targeted reductions in length of stay will be needed to avoid the unexpected consequence of the renovation (additional floor bed utilization), and maintain throughput in the system. Total bed days of care per 1000 unique patients is targeted to shrink nationwide to 1328 in the year 2000 (VHA Performance 2000 plan). Modeling in advance of the renovation provided an opportunity to develop length of stay reduction strategies to meet the floor bed needs including increased use of case management, home health care, and disease management guidelines.

It will be important to further validate this model by comparing the actual outcome after construction with the model's results. It must be recognized, however, that significant differences in the results may occur due to differences in the input variables. Changes in referral patterns and efforts to reduce LOS may significantly alter the outcome. The model will be useful as these new strategies are developed.

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