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A SIMULATION MODEL FOR EVALUATING PERSONNEL SCHEDULES IN A HOSPITAL EMERGENCY DEPARTMENT

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ABSTRACT

This paper describes an Arena simulation model of a particular hospital's emergency department. The model allows the simulation of the process flows of 13 different types of patients, and is used to evaluate various feasible schedules for nurses, technicians, and doctors. The main performance measure used in the evaluation process is the average length-of-stay of patients in the emergency department.

1 INTRODUCTION

Recent years have seen an increase in the use of mathematical modeling techniques for the design and operation of health care facilities. For example, specialized simulation software packages such as Med Model (McGuire, 1994) and the hospital template of Arena (Drevna and Kasales, 1994) have recently been developed. For an overview of modeling techniques used in health care settings, see Pierskalla and Brailer (1991).

One of the main reasons for the increase in the popularity of modeling techniques in health care settings is pressure resulting from the desire to maintain a high level of quality for patient care while reducing (or at least not increasing) costs. Techniques of mathematical modeling, including those associated with simulation, statistical analysis, optimization, and multicriteria decision analysis, allow one to optimize the use of health care resources (e.g., through efficient scheduling of those resources) subject to various constraints.

This paper involves a discussion of a simulation model developed for an emergency department of a Louisville, Kentucky hospital. Emergency departments are especially important since the number of emergency room visits in the United States exceeds 86 million per year. In addition, approximately 30% of a hospital's admissions are through the emergency department and about 50% of a hospital's total revenue is generated from patients who use or come through the emergency department (see Hospital Statistics).

The main purpose of the simulation model, developed using the Arena software package, was to have a vehicle for investigating the desirability of various personnel schedules for the emergency department. See Draeger (1992), Iskander and Carter (1991), Kumar and Kapur (1989), Ladany and Turban (1978), and McGuire (1994) for additional examples of simulation models of emergency departments.

2 DESCRIPTION OF THE EMERGENCY DEPARTMENT

The emergency department under study consists of two areas: a full service emergency room (ER) and Emergency Care Express. Emergency Care Express is a "fast-track" emergency room service that treats minor medical emergencies from 11am to 11pm seven days a week. The focus of this study however was the full service ER which is operational seven days per week, 24 hours per day. This ER consists of 16 rooms, including two cardiac rooms, one ear-nose-throat (ENT) room, and one room for patients with behavioral health problems. The ER treats approximately 39,000 patients per year.

Concern about the ER was raised because the average patient time in the system was approximately 142 minutes, which was significantly greater than the standard industrial average of 120 minutes. Hence, the main objective of the study was to investigate various schedules for nurses, ER technicians, and doctors in order to reduce the average patient time in the system. Other objectives included providing management with better insight into the working of the ER and to determine how other factors (e.g., patient load) affected the average length of stay (LOS) of patients.

A patients enters the ER by one of two modes: Walk in or squad. Patients are assessed upon arrival by a nurse (RN) and urgency of care is prioritized. The RN initially assesses the patient and obtains baseline information such as vital signs and chief complaint. The physician then examines the patient and appropriate medication, laboratory tests or X-ray procedures are ordered. Patients receive a certain amount of direct care every hour during their length of stay based on their acuity. The activities performed by RN, technicians and physicians are of two types, one is direct and the other one is indirect. Direct treatments are hands-on type of treatment on patients. It includes assessing patient conditions, taking vital signs, applying dressings, hanging IV's, patient treatment etc. Whereas indirect time spent by the staff of the ER includes coordinating patient care with other departments, processing physician orders, handling communication, general administrative work, cleaning beds, assisting in hygiene etc. For physicians the indirect time includes communicating with other expert physicians for their comments and advice, and evaluating patient condition from X-rays and lab reports. Patients have a probability of leaving the ER for a period of time to go to ancillary departments such as X-rays etc. Patients leave the ER in one of the two ways: discharge to home or admission to the hospital. In either case they leave the model/system and they no longer require care from the ER staff.

For this study, patients were classified according to 13 significant patient groups. Data was collected to establish the fraction of patients in each group -- see Table 1. Associated with each group of patients was a particular process flow, as defined by a sequence of activities and associated resource types (doctors, nurses, technicians) required to perform those activities. For example, the process associated with patients who have cardiovascular disorders is shown in Figure 1. Note that this process flowchart includes some probabilistic branching, as is the case for most of the categories of patients.

Table 1: Categories of Patients

No.	DIAGNOSIS	PROBABILITY OF OCCURENCE (%)
1	Allergy	5
2	Cardio-Vascular Disorders	12
3	EENT	6
4	Gastro-Intestinal Disorders	13
5	Genito-Urinary Disorders	5
6	Gynec. & Obs. Disorders	5
7	Musculoskeletal Disorders	13
8	Neurological Trauma	7
9	Orthopedic	10
10	Psychiatric Disorders	4
11	Respiratory Disorders	10
12	Surgical Trauma	5
13	Others	5

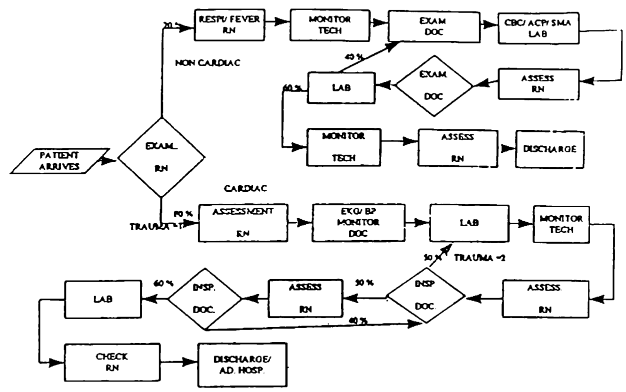

Figure 1: Process Flow for Patients with Cardiovascular Disorders

3 DATA COLLECTION

Data for building the model was collected on patient arrival rates; types of treatments for various categories of patients; resources (e.g., nurses, technicians, or doctors) and durations required for the various activities associated with the treatment of patients; possible schedules of nurses, technicians, and doctors; and indirect time spent by ER staff.

Some of this data was collected through the use of group discussions with some of the nursing staff. Other data (such as that associated with arrival rates for different types of patients) was collected from ER logs and patient records.

The current schedules used for the nurses, technicians, and doctors of the ER are given in Table 2. This data was used as input to the model for validation purposes.

Table 2: Current Personnel Schedules in the ER

RESOURCE	TIME					
	12mid-7a.m.	7a.m.-11a.m.	11a.m.-2p.m.	2p.m.-3p.m.	3p.m.-11p.m.	11p.m.-12 mid.
Nurses	4	4	6	6	7	4
Technicians	2	3	4	4	4	2
Doctors	1	1	1	2	2	2

4 SIMULATION MODEL DESCRIPTION

The development of the simulation model for the ER was accomplished by using Arena. In the model, the perspective used to describe the process is that of a patient flow in the

ER. The dynamic nature of the ER is captured by altering the time between arrivals of patients by time of the day. Patients arrive according to an interarrival distribution based upon the pattern identified for the time of day.

Parameters and attribute values (e.g., trauma level) are assigned upon arrival for each patient. Initially a trauma level value of 0 is assigned upon arrival and trauma values are changed in the model with improving or deteriorating condition of the patient with a value of 0 as lowest and 3 as the highest acuity level for trauma. Patient case type is assigned to each patient according to probability of occurrence of cases identified at the time of data collection. Specific patient care activities according to case type are grouped together and patients follow a process flow. Appropriate staff responsibilities are assigned at each node according to the flow chart made for patient type.

When a patient arrives, a trauma value is stored as an attribute value, and he is routed in the model according to a treatment type assigned with the help of a "branch" SIMAN node. The patient is routed in a sequence identified in the flow chart which was collected for each treatment type. The patient moves from one server to another, which represents appropriate treatment given to him. Hence, each server represents a treatment and the one resource: either RN, technician or doctor, selected to serve at that station. Inspection nodes are used when the decision is to be made about the condition of the patient and the next set of procedures. Finally when the patient passes through all treatment steps, he is routed to a depart node where all time-persistent statistics like length of stay etc. are collected.

Case type and acuity level determine the probability distribution applied in routing a particular patient through or around specific activities in the model. The priority of treatment is based on the acuity level of the patient. In the case of two or more patients attempting to capture one resource, the patient with the higher acuity is served first. In the case of a tie FIFO rule is used. Activity durations are dependent on patient treatment type and acuity level, and are represented by the appropriate distribution obtained from detailed observation data. In the case of lab and X-ray procedures, an average waiting time is built into the activity time since these locations (lab and X-Ray) are not modeled explicitly.

While modeling the system, exceptional cases and deaths in the ER are omitted, and the following additional assumptions are applied:

1. Each patient retains a single classification according to treatment, throughout his stay in the ER.
2. For the purposes of the model, the processing of patients according to treatment type was judged adequate to represent the process.
3. In the event that a staff person is busy with an activity at the end of his/her shift or during indirect time, that person finishes the activity before going off duty, as would actually occur in the ER.
4. For the purpose of simulation, the model was developed for the procedures done in the ER work area only. The triage work area where initial administrative work is done on a patient was not considered in the model due to lack of data; also, ER managers wanted to perform the analysis on only the internal working of the ER.
5. All staff resources are assumed to be available without any specific break time. In the real system, ER staff breaks are not scheduled, they occur whenever the staff gets free and senses there is a time to take a break.
6. It is not mandated that a single nurse treat a particular patient during the patients' stay.
7. Reneging patients, who choose not to wait after they were initially assessed, were not considered while modeling.
8. All persons of a particular resource type, were assumed to have the same level of expertise and skills.
9. The usage of a specialist doctor while treating a patient was not considered while modeling.

5 MODEL VERIFICATION AND VALIDATION

The model verification was performed using the trace and break option of Arena. The trace option records the movement of entities from node to node and the processing of entities at each node. The break option stops the simulation when a logical error occurs. The trace output report was examined to determine whether the entities were proceeding through the system as desired. After examining the trace it was determined that the computer program implementing the simulation model of the ER was executing properly.

Several steps were taken throughout the project to validate the model and build its credibility. These included an initial introduction of the ER managers and RN representative to the concept and objectives of simulation as an analysis tool. In identifying elements to be included in the model and determining appropriate levels of detail, the help of management engineering department was sought. Through the data collection process, first hand knowledge of the ER was gained across all shifts, including usual and exceptional patient cases. Those issues necessary to include in the model were prioritized and respectively addressed during development of the model.

The completed model was run on a pilot basis to perform first pass validation against actual data. The system performance measure monitored was total time spent by patients in the ER, which was of main interest to management in decision making. Relative frequency distribution of length of stay of patient in the ER (LOS) for the model's one week of activity was compared against actual results from patient observation data.

After initial validation, the ER managers were presented the model flow, the model assumptions and details, validation results and the output of the current model. Suggestions and corrections to the model details and assumptions were solicited from the ER managers.

Final model changes were made, the model was run with five replications and the results were validated against actual data. The average LOS of the simulation model was found to be 142 minutes. With 95% of confidence interval (CI), average LOS was found to be between 134 and 149 minutes. This compares to an actual average LOS for the ER of 142 minutes.

6 MODEL EXPERIMENTATION

Experimentation with the model is ongoing. Design variables and parameters with which one could experiment using the model include the mix of patient types; process activities, including durations of those activities; demand for the ER; and schedules for the nurses, technicians, and doctors. As was mentioned earlier, the emphasis in this initial effort was on the personnel schedules, as measured by the numbers of nurses, technicians, and doctors on duty in the ER for each hour of the simulation run.

In the production runs of the model 14 days of the operation of the ER were simulated, including a warm-up period of seven days. All statistics were cleared after the warm-up period but the entities were kept in the system in order to begin the simulation in a steady state mode.

Five different schedules, labeled A,B,C,D, and E, were input to the model for experimentation purposes. These schedules varied only in the numbers of nurses and technicians on duty from the actual system, and kept the numbers of doctors on duty the same as the actual system. See Table 3 for those five schedules.

Each of the five schedules was run for five replications, with the average LOS and a 95% confidence interval for average LOS computed in each case. These results are shown in Table 4. Note that Schedule D gave the lowest average LOS, but that additional replications would have to be made in order to establish significant differences between Schedule D and Schedules A and C.

Table 3: Experimental Personnel Schedules

RESOURCE	SCHEDULE	TIME			
		7a.m.-11a.m.	11a.m.-3p.m.	3 p.m.-11p.m.	11 p.m.-7a.m.
NURSES	A	4	6	7	5
	B	3	6	7	5
	C	5	6	7	5
	D	5	7	7	5
	E	5	7	7	4
TECH.	A	3	3	5	3
	B	4	5	5	3
	C	4	5	4	3
	D	3	4	5	3
	E	3	5	5	3

Table 4: Simulation Output Associated with the Experimental Schedules

SCHEDULE	AV. LOS	AV. LOS WITH 95% CI
A	137.2	131.9-142.5
B	143.3	140.5-146.3
C	138.8	135.3-142.3
D	136.9	134.0-139.9
E	143.3	136.3-149.7

7 CONCLUSIONS

A simulation model is an ideal tool to cope with the diversified and dynamic nature of a hospital's emergency department. The model developed for this work allowed the evaluation of various schedules for the nurses, technicians, and doctors with respect to such performance measures as average length of stay of the patients.

There are many extensions to this work which are currently being investigated. Examples of these extensions would include the development of an "optimization module" which would interface with the simulation model to optimize over a large number of potential schedules. Such an optimization module would consider several objectives simultaneously, such as length-of-stay, personnel costs, and desirability of various schedules as considered by the nurses, technicians, and doctors.

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