Revue française d'automatique, d'informatique et de recherche opérationnelle. Recherche opérationnelle

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Revue française d'automatique, d'informatique et de recherche opérationnelle. Recherche opérationnelle, tome 12, nº 1 (1978), p. 3-14.

<http://www.numdam.org/item?id=RO_1978__12_1_3_0>

R.A.I.R.O. Recherche opérationnelle/Operations Research
(vol. 12, n° 1, février 1978, p. 3 à 14)

THE DETERMINATION OF SURGICAL SUITE CAPACITY AND AN EVALUATION OF PATIENT SCHEDULING POLICIES (*)

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Abstract. — *This paper examines several aspects of the operation of a hospital surgical suite. The approach taken is comprehensive; the problem of determining the proper capacity of the suite in anticipation of an expanded bed complement is analyzed, the methodology for the generation of probability distributions that serve as input for the simulation of the system is developed, and an evaluation of alternative scheduling policy for various types of surgical patients is discussed. The application of the techniques described in this study not only adds insight to the planning function of health care delivery systems, but also offers the user substantial cost saving in the ongoing system's performance as demonstrated by the more effective use of the available facilities.*

I. INTRODUCTION

The ongoing operation of a modern hospital surgical suite presents many problems that must be solved on a day-to-day basis. Two basic problems, from an operational point of view, concern capacity and throughput. A lack of understanding of either of these two problems seriously jeopardizes the efficient operation of the surgical suite as one is a function of the other. However, the relationship between the two variables is frequently not defined. Because it was recognized that the determination of an optimum relationship was necessary in order to provide an efficient solution, it was decided at Deaconess Hospital to investigate the situation.

In the mid-1960's it was decided that 144 medical-surgical beds would be added to the hospital bed complement. This immediately raised the question in the surgical suite of what additional capacity would be required to accommodate the increased patient load in the operation rooms. In addition, the question was raised as to how much additional recovery-room time and space would be required to accommodate the increased patient load.

Thus, the primary problem that emerged was to determine the level of increased need for operating-room and recovery-room time and space, based on the increased bed complement. A secondary question that emerged was to determine the utilization level of the proposed new facilities using various policy constraints.

(*) Reçu août 1976, révisé février 1977.
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A two-step approach to the analysis of these questions was undertaken. First, to answer the question relative to time and space requirements for the operating rooms and recovery rooms, a simulation model was constructed using the Monte Carlo method. To investigate policy considerations, the original model was modified to reflect five different scheduling strategies. The result of the five scheduling strategies were then critically evaluated and compared.

The simulation model has been tested and its results facilitate management planning, decision making, and control by providing useful information.

II. THE ANALYSIS

The study relating to the construction of the original model was concerned basically with two elements.

First, it was necessary to project the increased values tor the surgical suite and the recovery room due to the increase of 144 beds in the bed complement.

The second step was to analyze the lengths of stay in the surgical suite for various types of surgical patients. A chi-square test was performed to ascertain the type of distribution that the sample represented. Based on the type of distribution, the model was developed and the results were indicated.

Method of study

The study was inductive. Data were collected from a sample (445) of the patients at Deaconess Hospital regarding the type of surgery that was performed as well as their average length of stay in the hospital for that type of surgery. The percentage of the various types of surgery performed on the total population of patients as well as their average length in the hospital were inferred from the sample results.

In addition, data were collected from a sample of patients regarding the length of stay in the operating room. The proportion of patients that fell into each time segment classification for the total population was inferred from the sample results. The time segments studied were in increments of one-half hour each. The simulation model was then developed incorporating these sample results.

Explanation of the study

An examination of the *Monthly Service Report* of the Deaconess Hospital revealed that 42% of the medical-surgical patients actually have surgery. The addition of 144 new Medical-Surgical beds indicated that approximately 60 of these beds would be routinely occupied by surgical patients.

A simple method of extrapolation was used to establish the absolute increase and percentage increase in cases expected for each of the surgical sections. The extrapolated figures assumed full bed utilization and the same patient mix. An example of the extrapolation follows:

An examination of the previous year's surgical records revealed that 4.5% of the total surgical cases were opthalmology cases. Furthermore the average length of stay for the opthalmology cases was 7.4 days. It is calculated that on the average 2.7 of 60 new surgical beds would be used by opthalmology patients ($0.45 \times 60 = 2.7$). Furthermore, 49 patients would be able to use each bed during a year ($362 \div 7.4 = 49$). The conclusion therefore is that there would be an increase of 132 opthalmology cases during a given year ($49 \times 2.7 = 132$). Table I shows absolute increase as well as the percentage increase in the total surgical cases.

TABLE I

Increase in surgical cases based on increased bed count

Type of Surgery	Increase in Number of Surgical Cases per Year
Ophthalmology	132
Gynecology	282
Urology	264
Orthopedic	202
ENT (Ear-Nose-Throat)	1,098
Dental Surgery	715
Other Major Surgery	683
Total Increase	3,376
Percentage Increase	53.6 %

For the year in which the study was being conducted, there were 6,293 surgical procedures performed. When the projected increased case load of 3,367 surgical procedures is added to the old case load, the projected new case load of surgical procedures is 9,660 or an increase of 53.6%.

The objective of this part of the analysis is to provide an estimate of what the new daily cases will be for purposes of the simulation. For example, if the average daily surgical case load had previously been 16.9 patients, a 53.6% increase due to the added bed complement would mean that the new projected average daily case load would approximate 25 patients.

Billing information from the Business Office provided sample data for length of stay in the operating room. Observation was used as the source of data to determine the length of stay in the recovery room. The results of the data relating to length of stay in the operating room is summarized in table II.

TABLE II

Lengths of stay in the operating room ([a])

Length of Stay in Hours	Frequency	Relative Frequency
.01 - .50	181	40.7
.51 - 1.00	103	23.2
1.01 - 1.50	64	14.4
1.51 - 2.00	42	9.4
2.01 - 2.50	22	4.9
2.51 - 3.00	18	2.9
3.01 - 3.50	8	1.8
3.51 - 4.00	5	1.1
More than 4.00	7	1.6
Total	445	100.0

([a]) The observations were not necessarily made on a continuous basis during a given period. Times were recorded to the nearest 5 minutes. One result of this method is that (n) (μ) for a given distribution in table II may not equal the number of hours indicated by the caption for that distribution. Another consequence is that table II contains no observations of zero lengths of stay. The discrete values of the first class interval (.08 to .50 hour) are .083, .166, .250, .333, .416, and .500 of an hour per surgical case.

TABLE III

Conversion of URN to REN

	Type of Surgery	Time Interval	P(t)	URN	REN
1.	E.N.T.		15.8	000-157	
2.	Urology (To R.R.)*		08.4	158-241	
3.	Urology (No R.R.)		08.5	242-326	.490
4.	Opthalomology (No R.R.)		05.8	327-384	
5.	All Other Surgery	.51 - 1.00	23.6	385-620	.728
6.	"	1.01 - 1.50	14.6	621-766	1.214
7.	"	1.51 - 2.00	09.0	767-856	1.699
8.	"	2.01 - 2.50	05.5	857-911	2.184
9.	"	2.51 - 3.00	03.4	912-945	2.700
10.	"	3.01 - 3.50	02.1	946-966	3.155
11.	"	3.51 - 4.00	01.3	967-979	3.641
12.	"	More than 4.00	02.0	980-999	4.021

* R. R. Stands for recoveryroom.

The frequencies of the length of stay in the operating room are distributed in a gamma distribution. More specifically, chi-square tests support the hypothesis that the sample frequencies are drawn from a population approximated by a *negative exponential distribution* $[P(t) = 1-e^{-\mu t}]$.

The mean amount of time spent by the patients in the operating room is 1.03 hour (μ = 1.03).

TABLE IV

A simulation example

URN	REN	Length of Operation	Time Operation Begins	Time Operation Ends	Operating Room Number	Recovery Room Yes	Recovery Room No	Time Recovery Begins	Time Recovery Ends	RR Bed No.	Time RR Bed Available
674	1.21	1.25	7.50	8.75	1			8.33	11.83	3	12.08
107	0.49	0.50	7.50	8.00	2	X		8.08	9.58	1	0.83
341	0.49	0.50	7.50	8.00	3		X	8.08	---	-	---
465	0.73	0.75	7.50	8.25	4			8.33	11.33	2	11.58
247	0.49	0.50	7.50	8.00	5		X	8.08	---	-	---
115	0.49	0.50	8.25	8.75	2	X		8.83	10.33	4	10.58
215	0.49	0.50	8.25	8.75	3	X		8.83	10.33	5	10.58
017	0.49	0.50	8.25	8.75	5	X		8.83	10.33	6	10.58
394	0.73	0.75	8.50	9.25	4	X		9.33	12.33	7	12.58
527	0.73	0.75	9.00	9.75	1	X		9.83	12.83	1	13.08
093	0.49	0.50	9.00	9.50	2	X		9.58	11.08	8	11.33
160	0.49	0.50	9.00	9.50	3	X		9.58	11.08	9	11.33
912	2.70	2.78	9.00	11.78	5	X		11.88	14.86	9	15.11
008	0.49	0.50	9.50	10.00	4	X		10.08	11.58	10	11.83
409	0.73	0.75	9.75	10.50	2	X		10.50	13.58	4	13.83
747	1.21	1.25	9.75	11.00	3	X		11.08	14.08	6	14.33
113	0.49	0.50	10.00	10.50	1	X		10.58	12.08	5	12.33
537	0.73	0.75	10.25	11.00	4	X		11.08	14.08	11	14.33
945	2.70	2.78	10.75	13.53	2	X		13.61	16.61	5	16.86
868	2.18	2.25	10.75	13.00	1	X		13.08	16.08	2	16.33
785	1.70	1.75	11.25	13.00	3	X		13.08	16.08	10	16.33
226	0.49	0.50	11.25	11.75	4	X		11.83	13.33	8	13.58
823	1.70	1.75	12.00	13.75	4	X		13.83	16.83	7	17.08
706	1.21	1.25	12.03	13.28	5	X		13.36	16.36	3	16.61
765	1.21	1.25	13.25	14.50	1	X		14.58	17.58	1	17.83
096	0.49	0.50	13.25	13.75	3	X		13.83	15.33	8	15.58
744	1.21	1.25	13.53	14.78	5	X		14.86	18.86	12	19.11

The data relating to the probability of various types of surgery is presented in table III. In addition, table III reveals that the uniform random numbers (hereafter referred to as URN's) generated from the simulation are used for two purposes. First, they serve as the basis upon which a conversion is made to a random exponential number (REN) (3). Secondly, in the case of the surgical procedures in the .01 – .50 time frame, the URN is used to determine whether or not the patient goes to the recovery room.

Empirical evidence demonstrates that the mean amount of time in the recovery room for minor surgical procedures is 1.5 hour while the mean amount of time in the recovery room for major surgical procedures is 3 hours. Table III

(3) A complete explanation of the conversion process from a URN to an REN is given in Schmitz and Kwak [17].

displays the data illustrating the URN from 000-384 generate minor surgical procedures while the URN from 385-999 generate major surgical procedures in the model. An analysis of the empirical data revealed that approximately 38% of the surgical cases are considered to be minor surgery while 62% of the surgical cases are considered to be major surgery. While it is possible to develop a refined model to simulate the length of stay in the recovery room, preliminary testing suggested that the level of precision for such a refined model would not be substantially greater than use of the raw averages.

III. THE MODEL

Simulation rules and disciplines

1) The uniform random numbers (URN) are generated and must be different for each day.

2) All of the minor surgical procedures (ear, nose, throat, urology, and ophthalmology) have an average length of stay in the operating room of .50 hour.

3) Only 50% of the urology cases go to the recovery room. The other 50% do not go because the procedure was performed under a local anesthetic. Whether or not a patient goes to the recovery room is determined by the URN as described in table III.

4) All of the ear, nose, and throat surgical cases go to the recovery room. Because these cases are considered to be minor surgery, their length of stay in the recovery room is 1.5 hour.

5) Ophthalmology cases do not go to the recovery room.

6) The beginning time for the surgical schedule is 7:30 a.m.

7) The "make ready" time in the operating room is .25 hour.

8) Transportation time from the operating room to the recovery room is 08 hour (5 minutes).

9) The "make ready" time in the recovery room is .25 hour.

10) The first operating room that is vacated is the first one that receives the patient.

11) The first recovery-room bed that is vacated is the first one to be used when the need arises.

Explanation of the simulation model

The simulation was conducted by varying the number of operating-room beds and recovery-room beds available in order to arrive at an optimum number of beds in each case. Table IV is an illustration of the simulation of one day's activity. Its interpretation is as follows:

1) Using a table of random numbers, a URN was selected.

2) Utilizing table III the URN is connected to an REN. Since the URN is 674, the corresponding REN is 1.21.

3) The REN is then multiplied by the mean amount of time in the operating room (1.03 hour) producing a simulated length of stay in the operating room of 1.25 hour.

4) When this length of stay is added to the beginning time of the operating room schedule (7.50 hours), the ending time of the surgical procedure is at 8.75 hours.

5) When travel time of .08 hour is added to the ending time of the surgical procedure, the arrival time of the patient in the recovery room is 8.83 hours.

6) It is interesting to note that the first patient on the surgical schedule is actually the third patient to enter the recovery room. Furthermore, in scanning the column headed "Time RR Bed Available," we find that the first recovery-room bed does not become available for reuse until 9.83 hours.

7) In that this is a major surgical case (all cases with a URN over 385 are major surgical cases), 3 hours are added to the arrival time in the recovery room in order to calculate the departure time, which is 11.83 hours.

8) When make ready time of .25 hour is added to the departure time, we find that bed number 3 will become available for reuse at 12.08 hours.

In order to simulate the new surgical load, a schedule of 27 patients was run using varying numbers of operating rooms and recovery-room beds available. The simulation indicated that the optimum number of operating rooms, given the 8-hour work day and "other" economic constraints being assumed, should be five. Given these five operating rooms and a randomly generated surgical schedule, the maximum number of recovery-room beds being utilized at peak use was 11. Thus the original problem of capacity, which was defined in the introduction, was solved by use of this model.

The problem of throughput

The second problem considered was that of throughput. Since the original model had already been constructed, it was a relatively simple matter to modify it in such a way that priorities of entry to the operating room or recovery room could be established. In order to test whether or not throughput could be improved, five policy strategies were formulated and tested. They were as follows:

Strategy I: This is the strategy of random arrivals at the operating room and is a replication of the hospital operation (baseline strategy).

Strategy II: This strategy dictates that patients requiring the use of recovery-room facilities are given a priority. Furthermore, this priority is given without regard for length of stay in the operating room.

TABLE V

Comparison of strategies

A. Operating-Room Utilization Rates[(a)]

Day	Strategies I	II	III	IV	V
1	0.639	0.639	0.699	0.698	0.685
2	0.633	0.700	0.693	0.639	0.693
3	0.545	0.582	0.582	0.557	0.582
4	0.626	0.640	0.653	0.640	0.626
5	0.678	0.693	0.714	0.687	0.708
6	0.637	0.668	0.652	0.637	0.668
7	0.617	0.630	0.617	0.604	0.631
8	0.684	0.684	0.668	0.668	0.683
9	0.648	0.658	0.688	0.687	0.700
10	0.731	0.751	0.733	0.717	0.754
Average	0.6438	0.6645	0.6699	0.6534	0.6730

B. Recovery-Room Utilization Rates[(a)]

Day	Strategies I	II	III	IV	V
1	0.302	0.302	0.331	0.330	0.324
2	0.354	0.391	0.387	0.357	0.387
3	0.367	0.392	0.393	0.375	0.392
4	0.415	0.424	0.433	0.424	0.415
5	0.359	0.367	0.378	0.363	0.375
6	0.409	0.429	0.419	0.409	0.429
7	0.349	0.356	0.348	0.341	0.356
8	0.432	0.432	0.423	0.423	0.432
9	0.313	0.318	0.332	0.332	0.338
10	0.375	0.386	0.376	0.368	0.387
Average	0.3675	0.3797	0.3820	0.3722	0.3835

C. Queueing at the Recovery-Room Facility[(b)]

Day	Strategies I	II	III	IV	V
1	0	0	0	0	0
2	0	0	497	0	0
3	0	0	306	363	0
4	0	0	244	0	251
5	0	0	241	0	0
6	0	0	0	0	0
7	0	0	498	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	579	496	0
Average	0	0	236.5	85.9	25.1

TABLE V (*suite*)

D. Time of Last Departure from the Recovery Room[c]

Day	Strategies I	II	III	IV	V
1	18.588	18.082	17.335	17.589	17.836
2	19.080	18:325	18.578	18.834	18.326
3	18.329	17.583	16.834	17.585	16.836
4	17.337	17.329	16.578	17.092	16.837
5	18.836	18.335	18.835	19.080	18.828
6	19.082	18.081	17.581	18.335	17.827
7	17.335	16.826	17.080	17.834	17.082
8	19.335	18.867	18.336	18.836	18.582
9	17.344	16.334	16.869	17.623	16.829
10	16.837	16.328	17.082	17.327	16.084
Average	18.210	17.609	17.511	18.014	17.507

E. Time at which First Patient Enters the Recovery Room[c]

Day	Strategies I	II	III	IV	V
1	9.584	8.334	9.579	9.579	8.335
2	9.080	8.579	10.079	10.079	10.080
3	8.334	8.334	9.080	9.080	8.335
4	8.334	8.334	9.080	9.080	8.335
5	8.579	8.579	10.079	10.079	10.080
6	8.334	8.334	9.579	9.579	8.580
7	8.334	8.334	9.579	9.579	8.335
8	8.334	8.334	9.579	9.579	8.335
9	8.334	8.334	9.579	9.579	8.335
10	8.334	8.334	9.579	9.579	8.335
Average	8.558	8.383	9.579	9.579	8.709

([a]) Figures are utilization rates based on the duration of the simulation day, not a 24-hour day.
([b]) Units are in thousandths of an hour. Average excludes zero entries to the queue.
([c]) Surgical schedule begins at 7:30 a.m. (7.500 hours into the simulation day).

Strategy III: This strategy provides that those patients with the longest stay in the operating room are operated on first. Those that require the use of recovery-room facilities are scheduled last in descending order of their length of stay in the operating room.

Strategy IV: This strategy stipulated that those with the longest length of stay in the operating room are operated on first. However no queue discipline is applied to those patients that do not require recovery-room facilities (as was the case with strategy III).

Strategy V: This strategy dictates that categories 8 through 12 of table III are given a priority on the basis of longest length of stay in the operating rooms first. Those patients not requiring recovery-room facilities are scheduled last. Categories 1 through 7 of table III are served after the first group in descending order of length of stay in the operating room.

TABLE VI

Strategies				
I	II	III	IV	V
9.652	9.226	7.932	8.435	8.799

In order to efficiently run the many replications of the model that would be required, the model was programmed in GPSS and run on an IBM 370/168. Key statistics describing the dynamic properties of the system being simulated are automatically maintained in GPSS and can be easily captured by the researcher. A small sampling of the tabulated results is presented in table IV. These results tend to illustrate the effects of various strategies but are not inclusive of all relevant statistics generated by the GPSS model. The results of the various strategies are reported in tables V (A through E).

Table V C reveals that strategies III, IV, and V cause queueing at the recovery room. This is because these strategies cause the major surgical cases to be completed more quickly; thus the patients arrive at the recovery room earlier and in a much heavier volume. Note that strategy I shows the no queueing which is indicated by the fact that the recovery-room capacity was properly matched to the operating-room capacity in the baseline study (strategy I).

When tables V D and E are compared it becomes clear that the difference between the average recovery-room start and finish is markedly better for strategy III. Table VI shows this comparison.

These results are a significant finding for this study. They indicate a potential shortening of the work day in the recovery room of 1.72 hour per day over the baseline strategy which represents observed performance. More importantly, the adoption of strategy III offers the potential of scheduling personnel on a standard 8-hour day with the attendant elimination of overtime pay.

Based on the data from the simulation model, Deaconess Hospital is now giving serious consideration to the evaluation of the comparative costs of expanding the recovery-room capacity to 13 beds due to the possibility of a dramatic reduction in the average work-day for the recovery room.

IV. CONCLUSION

The simulation approach allows the evaluation of various scheduling strategies in the operating room and recovery room without disrupting the daily activities of a very sensitive area of the hospital. It should be pointed out that these strategies were representative, but not exhaustive, of the various scheduling alternatives available in a hospital operating-room setting. However, the study did demonstrate that scheduling policies could affect the efficiency of a given department and that potential improvements can be made. Furthermore, the baseline strategy, which represents current practice, is definitely inferior to some of the alternatives. Incorporation of any one of the strategies tested would involve little or no additional cost while permitting a significant reduction in manpower requirements.

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