International Journal of Engineering & Scientific Research
Vol. 6 Issue 3, March 2018,
ISSN: 2347-6532 Impact Factor: 6.660
Journal Homepage: http://www.esrjournal.com Email: esrjeditor@gmail.com Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Optimization of Waiting Time in Hospitals – A Case Study

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ABSTRACT

In this paper we present a system-wide model developed to allow management to explore trade-offs between operation rooms (OR) availability, bed capacity, surgeons' booking privileges and wait lists. We are interested to develop a goal programming model to schedule surgical slots for each specialty into ORs and applied it to the hospitals in a NIIMS hospital, located at Hyderabad considering OR time availability, post-surgical resource and waiting time of the patients constraints. The results offer promising insights into resource optimization and wait list management, showing that without increasing post-surgical resources. Hospitals could handle more cases by scheduling specialties differently. Scheduling surgical specialties in a medical facility is a very complex process.

KEY WORDS

Goal programming, operating rooms, waiting time.

DATA OF THE PROBLEM

This study was carried out in NIIMS Hospital which is located at the prime center of the twin cities of Hyderabad and Secunderabad, and spread over an area of about 23 acres. It has the constructed area of more than six lakh sq.ft. The recently constructed giant structure, i.e., Millennium Block, itself has added an area of about one sixth of the total space. This Institute extends its services through 28 Departments. Out of them, 16 are Super and Broad Specialties and others are Supporting Departments. The Institute has bed strength of 985 beds, out of which 684 are in General Wards, 117 in private rooms and 184 in emergency and post-operative care. The average number of out-patients visiting the hospital per day is about 1275, and the number of in-patients admitted per day is about 80. The average bed occupancy is over 89%.As on date, this University has cadre strength of about 2219 staff members. which includes Faculty-139, Residents (students)-172, Junior and Senior Residents-43, Medical Officers & Senior Medical Officers-14, College of Nursing & School of Nursing-6, College of Physiotheraphy-6, Offcers-14, Ministerial-149, Paramedical-304, Nursing-426, Class IV-115, Consolidated Staff-21, Fessey workers about 810 and the remaining for other categories. Interestingly NIMS has been consistently maintaining a very good patient doctor ratio of about 3:1

Cardiothoracic Surgery

Cardiothoracic Surgery Department was started in the year 1970. It was recognized as Post Graduate Training centre for M.Ch. Cardiothoracic Surgery since 1982. Ever since it has been serving the people of Andhra Pradesh, performing more than 1500 heart and lungs surgeries per year. A dedicated team of professionals including Doctors, Nurses, Perfusionists and other technical staff work all round the clock throughout the year to ensure the smooth conduct of this successful programme. The department has exclusively seven senior doctors as faculty including head of the department and twelve junior doctors. They are offering various courses for doctors and nurses to master them in cardiac service. They are doing several research projects. The regular outpatient services are provided on all the week days between 8am &1pm, specialty clinics are conducted between 2pm & 4pm, evening clinics are conducted between 4pm & 7pm.

Major Equipment:

Ors

1. Operation tables - (5)
2. Valley lab cautery machines - (5)
3. Defibrillators (Philips model) - (4)
4. Pacing systems - AV sequential pacing - (2)
5. Sarns 9000 heart lung machines (colour screen) & TCM – (4)

CT ICU

1. Ventilators – (10)
2. Syringe pumps – (60)
3. Multi channel Monitors with ECG, IBP, SP O2 – (14)

Specialized Procedures:

1. Mitral Valve Repairs
2. Aortic Aneurysm Repairs
3. Total Arterial Revascularization
4. Congenital Heart
5. Surgeries Support services to other specialties (Isolated limb perfusion, Deep Hypothermic Circulatory Arrest etc).

The main priority with respect to cardiac surgical activity for the current year is that no patient should stay on the waiting list for more than six weeks. Therefore, the hospital will try to determine the maximum surgical activity level, taking into account its estimates of incoming patients, operating room availability, as well as its current resources. This way, the extraordinary activity will also be determined that is, the patients that have to be referred to other hospitals

The required information is given in the following tables:

Table 1: Activities and Variables Corresponding to the Cardiac Surgery Service.

S. No	Code No	Name of the Operation	Time(min) for operation	Arrangement time(min) for the operation
1	C01	ASD	90-120	30-45
2	C02	VSD	90-120	30-45
3	C03	CABG	180-240	30-45
4	C04	MVR	90-120	30-45
5	C05	AVR	90-120	30-45
6	C06	DVR	200-240	30-45
7	C07	ICR	240-300	30-45

Table 2: Expected Admissions during the Planning Period of the Cardiac Surgery Service.

S. No	Name of Operation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	ASD	15	13	10	12	15	11	13	15	14	10	12	14
2	VSD	10	8	9	8	7	11	9	10	8	9	10	11
3	CABG	70	72	69	71	68	70	67	68	70	72	69	71
4	MVR	50	55	58	56	53	58	55	60	56	59	56	55
5	AVR	50	54	52	58	59	60	51	53	55	56	55	59
6	DVR	32	33	30	38	40	35	36	34	38	37	39	40
7	ICR	18	16	19	20	19	16	15	19	20	20	17	15

Table 3: Expected Exclusions without Operations during the Planning Period of the Cardiac Surgery Service.

S. No	Name of Operation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	ASD	1	0	0	1	2	0	1	0	0	1	0	1
2	VSD	0	0	1	0	1	0	0	1	0	0	1	0
3	CABG	2	0	1	2	1	1	0	2	3	0	1	1
4	MVR	1	0	2	1	0	0	2	1	1	0	1	1
5	AVR	0	1	1	0	1	2	1	0	1	1	0	1
6	DVR	1	1	0	1	1	0	1	0	0	1	1	0
7	ICR	0	0	1	0	0	1	1	1	0	0	1	0

Table 4: Initial State of Waiting Lists in the Cardiac Surgery Service.

C01	C02	C03	C04	C05	C06	C07
5	4	6	8	9	6	5

Table 5: Operating Room Minutes assigned to the Cardiac Surgery Service.

Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
6600	6000	7200	6600	7200	6600	7200	7200	7000	6900	7000	6900

Table 6: Parameters S_i^j Corresponding to the Cardiac Surgery Service.

Parameters S_i^j Corresponding To The Cardiac Surgery Service													
S.No	Name of operation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	**ASD**	21	34	36	42	58	64	73	77	81	90	95	99
2	**VSD**	26	32	39	44	49	51	58	65	72	80	84	88
3	**CABG**	84	89	97	114	121	129	138	146	151	165	176	189
4	**MVR**	71	78	83	97	112	118	124	131	142	151	163	172
5	**AVR**	73	82	94	102	121	132	138	144	149	159	166	170
6	**DVR**	46	51	62	74	92	101	111	120	126	131	139	148
7	**ICR**	27	36	42	58	61	73	84	95	102	115	121	139

GOAL PROGRAMMING MODEL

General Goal Programming model can be presented as follows:

$$\text{Min} \quad \sum cd$$

$$\text{Subject to } Ax + Rd = b \text{ ; } \quad x, d \geq 0$$

The objective function (min cd) is simply a minimization function of deviational variable with certain priority factors and weights assigned to them. A number of variations in the objective function may be achieved according to the goal structure of decision analysis.

Constraints

The model constraints can be grouped as follows:

(A) State equations.

(B) Available operating room time for operations.

(C) Limitations on the overall ordinary

(D) Bounds on the extraordinary activity levels.

With the simple notation, the constraints have described as follows:

(A) State Equations:

$[n1]_i^j$ $$WC_i^{j+1} = WC_i^j + AC_i^j - EC_i^j - XC_i^j - C_i^j$$

where i = 1,2,…,7 ; j = 1,2,3……12

where C_i^j denotes the number of operations i performed in the month j , XC_i^j denotes the extraordinary number of operations i performed in the month j, WC_i^j denotes the state of the waiting list for process *i* at the beginning of month *j*, AC_i^j is the estimated number of admissions for process i during month j, EC_i^j represents the estimated number of exclusions without surgical operation for process i, each month j. The values of AC_i^j, EC_i^j and the initial values of the waiting lists are displayed in Tables 2, 3 and 4 respectively.

(B) Monthly Operation Room Availability:

The available operation theatre times are computed, considering that the maximum daily activity is seven to seven and a half hours. Besides, it is assumed that the operating room sessions are previously assigned to each service due to intern agreements, and cannot be changed at this state of the process. At the most three operations can be performed in a day.

The duration of each process, C_i (which can be seen in Table 1), has been determined using the mean data obtained from the operating room reports plus thirty to forty five minutes, which is the time needed to prepare the operating room for the next operation. This, the constraint corresponding to month *j* takes the following form;

$[n2]^j$ $\qquad \sum_{i=1}^{7} c_i C_i^j \leq CQ^j$ $\qquad$ where j=1,2,3……12

Where the right-hand side, CQ^j, is the total operation room available time for the cardiac surgery service in month j, and it can be seen in Table 5.

(C) Lower Bound On The Global Ordinary Activity Level:

This constraint is formulated as the overall sum of the ordinary activity along the planning period. The right hand side has been fixed to 2400 operations, which is the minimum operation number as the cardiology department has 4 operation theaters. In this study, several efficient solutions regarding the maximization of the ordinary activity and the minimization of the extraordinary activity were most discussed. Thus, the constraint is as follows:

$[n3]$ $$\sum_{i=1}^{7}\sum_{j=1}^{12} C_i^j \geq 2400$$

This fact, together with the possible existence of multiple solutions of the problem, makes it necessary to assure a minimum number of ordinary operations should perform, so as not to waste the resources of the hospital.

(D) Bounds on the Extraordinary Operations:

To minimize the extra-ordinary operations a target value is set on to this number. In all the services, there exist bounds on the extraordinary activity, due to contractual and/or technical reasons. After that, it was decided that:

- no extraordinary service is needed for ASD and VSD operations :

  $[n4]^j$ $\qquad XC^j_1 + XC^j_2 = 0$ $\qquad$ where j=1,2,3, ...,12

- Together there must be at the most monthly 15 extraordinary services will be utilized for the operations 3,4,5 and 6

  $[n5]^j$ $\qquad \sum XC^j_i \leq 15$ $\qquad$ where i=3,…6 and j = 1,2,3,......,12

Goals

In this problem the goals are to reduce to six weeks the maximum stay on the waiting lists, and to limit the number of extraordinary operations. Thus, these goals are divided into two priority levels. The first level contains the waiting list goal, while the extraordinary activity limitation is in the second level and the maximum utilization of operating room. Next, let us build the equations that reduce the maximum stay on the waiting list to six weeks. To this end, it must be assumed that the sum of the ordinary and extraordinary operations performed between that particular month to the j^{th} month must be greater than the number of patients that would be on the waiting list for six weeks or longer for each process i in month j. Thus, the constraint is as follows:

$$\sum_{i=1}^{7}\sum_{j=1}^{12}[C_i^j + XC_i^j] \geq S_i^j$$

The meaning of these equations is setting a lower bound on the ordinary activity level of each process, so as to accomplish the maximum stay requirements. These lower bounds must be fixed for each process and month. The right-hand parameters per process, which are displayed in Table 6, have been determined taking into account the data of Tables 2, 3 and 4, as well as the time of stay in the waiting list of the patients at the beginning of the planning period.

Therefore, the formulation of these goals is the following:

$$\boldsymbol{G1}: \qquad \sum_{j=1}^{12}[C_i^j + XC_i^j] + d_i^{-j} - d_i^{+j} = S_i^j$$

where i = 1,2,.....,7

where d^{-j}_i and d^{+j}_i are the corresponding negative and positive deviation variables, respectively.

This way, 84 goals are considered, that is, one per process and month. The achievement function corresponding to the first priority level is the sum of the corresponding negative deviation variables:

$$h_1(d^-, d^+) = \sum_{i=1}^{7}\sum_{j=1}^{12} n_i^j$$

The second goal, as previously mentioned, sets a limitation on the total extraordinary activity and the maximum utilization of operating room. For this reason, a cost is assigned to each extraordinary activity variable, which is decreasing in time, so that the final solution does not accumulate all the extra activity at the beginning of the planning period. This way, the activity is carried out at a higher cost only if it is necessary in order to accomplish the waiting list requirements.

The function corresponding to this goal is the following:

$$\sum_{i=1}^{7}\sum_{j=1}^{12}[\propto^j XC_i^j]$$

Namely, the condition $\propto^j + j = 21$ is imposed, where $\propto^j$ is the cost assigned to month j, independent of the service and process. This condition implies that such cost decreases as the months pass, and therefore the extraordinary activity is done at high cost only when it is strictly necessary. In Rodriguez, a study was carried out in order to determine a set of efficient solutions relative to the objectives of decreasing the waiting lists and minimizing the number of extraordinary operations. These results were shown to the decision makers when they were asked to give a target value for this second goal, and the value 1891 was chosen. Anyway, the setting of target value is always a complex process, and of course, the GP model itself is not affected by this particular value, although the final solution would be different. Thus, denoting the negative and positive deviation variables by xd^- and xd^+, respectively, the second goal takes the form:

$$\boldsymbol{G2}: \quad \sum_{i=1}^{7}\sum_{j=1}^{12}[\propto^j XC_i^j] + xd^+ - xd^- = 1891$$

Where the positive deviation variable is the non-desired one:

$h_2\,(d^-, d^+) = xd^+$

Obviously, any other cost-decreasing cost structure can be used for this goal in order to achieve the above-mentioned purpose. In this case, the study would have to be carried out again, in order to set the target value, which depends on the value of $\propto^j$.

Objective function

optimize $z = \sum_{i=1}^{7} p_i\,(d_i^-) + \sum_{j=1}^{12} p_i\,(d_j^- + d_j^+)$ such that all variables are non-negative.

RESULT AND ANALYSIS

The solution will be obtained by using the QSB^+ software may be interrupted as follows. Table 7 shows the different activity levels and evaluation the surgical waiting lists.

Table 7 Solution of the problem

Proess1	Proess2	Proess3	Proess4	Proess5	Proess6	Proess7	Proess8
Evolution of the waiting list							
Jan	41	42	112	97	98	72	56
Feb	38	41	109	95	94	71	54
Mar	35	41	107	92	90	69	51
Apr	36	38	106	89	89	66	50
May	32	37	101	87	88	64	49
June	30	34	99	81	86	63	42
July	28	35	98	78	82	61	41
Aug	28	32	95	75	81	58	39
Sep	27	31	96	76	78	37	57
Oct	25	29	91	74	75	56	36
Nov	24	27	89	71	71	52	31
Dec	22	24	88	70	68	51	30
Ordinary Activity							
Jan	1	8	4	12	11	28	10
Feb	3	2	12	21	29	19	0
Mar	0	5	23	45	12	22	9
Apr	2	4	22	28	11	18	10
May	0	0	18	30	12	21	14
Jun	0	6	21	28	10	26	16
Jul	4	9	32	38	9	14	15
Aug	1	8	17	31	14	25	11
Sep	2	10	39	22	18	21	9
Oct	0	8	31	28	13	20	14
Nov	0	7	26	35	12	19	13
Dec	4	14	29	39	10	12	6
Extraordinary Activity							
Jan	0	0	4	5	3	3	0
Feb	0	0	3	5	4	3	0
Mar	0	0	3	4	4	4	3
Apr	0	0	4	2	5	4	0

May	0	0	2	3	5	5	0
June	0	0	5	4	3	3	4
July	0	0	2	3	5	5	0
Aug	0	0	2	5	4	4	0
Oct	0	0	3	4	4	4	4
Nov	0	0	3	3	5	4	0
Dec	0	0	1	5	4	5	0

First goal correspond to the stay in the waiting list of patients beginning of the planning period is fully achieved. The second goal corresponds to the minimizing the number of extraordinary operations is also fully achieved.

CONCLUSION

In this paper we discussed large scale hospital has bed strength of 985 beds, out of which 684 are in general wards, 117 in private rooms and 184 in emergency and post-operative care. We developed a goal programming model to schedule surgical slots for each field into operating rooms and applied it to the hospitals by considering operation room time availability, post-surgical resource and waiting time of the patients constraints. The choice of schedules and resource availability impact directly on the number of patients treated by specialists, cancellations, waiting times and the overall performance of the system has improved.

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