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Surgical Subspecialty Block Utilization and Capacity Planning

A Minimal Cost Analysis Model

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Background: **Operational inefficiencies in the use of operating rooms (ORs) are hidden by traditional measures of OR utilization. To better detect these inefficiencies, the authors defined two new terms, *underutilization* and *overutilization,* and illustrated how these measures might be used to evaluate the use of surgical subspecialty ORs. The authors also described capacity planning (optimizing surgical subspecialty block time allotments) using a minimal cost analysis (MCA) model.**

Methods: **The authors evaluated *post hoc* all surgeries performed over 6 yr at a large teaching hospital. To prepare utilization estimates, surgical records were categorized relative to budgeted OR block time for each subspecialty. Surgical cases beginning and ending during budgeted OR block time were categorized as *budgeted utilization,* budgeted time not used for surgery was *underutilization,* and cases beginning before/after budgeted block time were classified as *overutilization.* Cases that overlapped budgeted and nonbudgeted OR block time were parsed and the portions were assigned appropriately.**

Probability distributions were fitted to the historical patterns of surgical demand, and MCA block time budgets were estimated that minimized the costs of underutilization and overutilization for each subspecialty. To illustrate the potential savings if these MCA budgets were implemented, the authors compared actual operational costs to the estimated MCA budget costs and expressed the savings as a percentage of actual costs.

Results: **The authors analyzed data from 58,251 surgical cases and 10 surgical subspecialty blocks. Classic utilization for each block-day by surgical subspecialty ranged from 44–113%. Average daily block-specific underutilization ranged from 16 to 60%, whereas overutilization ranged from 4 to 49%.**

Conclusions: **Underutilization and overutilization are important measures because they may be used to evaluate the quality of OR schedules and the efficiency of OR utilization. Overutilization and underutilization also allow capacity planning using an MCA model. This study indicated that the potential savings, if the MCA budgets were to be implemented, would be significant. (Key words: Capacity expansion; minimizing surgical costs; operational costs, budgeted costs.)**

THIS article is concerned with measuring operating room (OR) utilization, analyzing the quality of surgical schedules, cost reduction, and *capacity planning* (optimizing surgical block time allocations). We introduced previously two new measures, underutilization and overutilization, which we applied to allocating the surgical time budget for an entire suite of 18 ORs.[1] But surgical capacity is often scheduled as "blocks" of operating time assigned to specific surgical subspecialties. *Surgical blocks,* as defined herein, refer to groups of one, two, or three ORs administratively reserved for the nearly exclusive use of various surgical subspecialties. In this manuscript we demonstrate how under- and overutilization can be used to determine whether the use of subspecialty block time is efficient. Because surgical suites are one of the most costly functional areas in modern hospitals, they affect the financial health of the institution[2–5] and, hence, must be used efficiently.

The classic definition of *OR utilization* needs to be improved. As encountered in the literature, *classic utilization* is defined as the ratio of the total OR time used to the total OR time allocated or budgeted.[6,7] This definition of utilization is inadequate because it fails to differentiate the quality of utilization. Consider a simple example: a single OR is budgeted for 8 h with two

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surgeries scheduled, each of 4-h duration. If the surgeries are performed consecutively within the budgeted work day, classic utilization is measured as 100 (4 + 4) ÷ 8 = 100%, with no wasted resources. By contrast, consider the same OR when one 4-h surgery is performed during regular hours and the other is performed entirely after hours. In the latter scenario there are 4 h in which an expensive OR sits unused and 4 additional h for which personnel must be recalled and overtime costs apply. Each scenario is an example of 100% classic utilization, but in the latter there is both under- and overutilization, with penalties to the staff and institution inherent in each. If the exact OR time allotment is used, *i.e.*, no under- or overutilization, then scheduled (budgeted) time is used *efficiently*. *Underutilization* and *overutilization,* as defined herein, are important measures because they may be used to evaluate the quality of OR schedules and the efficiency of OR utilization.

We also describe a method of capacity planning based on measures of under- and overutilization that may prove useful to OR managers. The correct use of the model requires collection of historical data from surgical subspecialties and the relative costing of over- and underutilization. A minimal cost analysis (MCA) model is then used to estimate subspecialty *time budgets* (block time allocations) that minimize the cost of scheduling surgical procedures. Opportunities for cost savings may be detected by multiplying the block time allocations by an hourly rate to arrive at MCA budget estimates that can be compared with costs of actual operation. Our model is based on the well-known methodology of lot sizing and inventory control available in the operations research literature[8] and is useful because it (1) improves the efficiency of the system in which it is deployed, (2) measures more accurately the effect of decisions that alter scheduling and utilization, (3) assists in capacity planning, and (4) helps detect opportunities for cost savings.

Methods

We evaluated computerized records[9] of all surgical cases performed at a large teaching hospital over a 6-yr period from 1989–1995. Independent variables in the data were surgical procedures by date, birth date, type of anesthesia, emergency status, gender, 9th International Classification of Diseases (ICD-9 code),[10] anesthesia start time, surgical preparation time, surgical start time, surgical end time, anesthesia end time, Current Procedural Terminologies (CPT) code,[11] location (surgical suite), anesthesiologist, surgeon, and admission status (inpatient *vs.* outpatient). All cases were evaluated by the surgical subspecialty blocks to which they were assigned. Use of the anonymous patient record was approved by the human subjects review committee of the institution that collected the data. Weekends were not analyzed and holidays were eliminated by omitting weekdays in which the total amount of time for which the combined 18 ORs were busy was less than 40 h.

Utilization of Subspecialty Blocks

To analyze utilization of surgical subspecialty ORs it was necessary to define several important new terms. *Usage* was the total time an OR was used, *i.e.*, the surgical demand, to be distinguished from *utilization*, which was the ratio of OR time used to that which was available. Utilization was a relative term without units, whereas usage was an absolute measure defined in minutes or hours. *Classic utilization* was the ratio of total time used to OR time budgeted. *Budgeted utilization* was the ratio of budgeted time used for surgery to budgeted OR time. Budgeted OR time not used was defined as *underutilization*, whereas surgical cases beginning/ending outside budgeted OR time were categorized as *overutilization.* Surgical cases that overlapped budgeted and nonbudgeted OR time were parsed and the portions were assigned appropriately.

We measured usage for each of 10 subspecialty surgical block allocations and quantified over- and underutilization specific to each block (see Appendix for a more detailed explanation of under- and overutilization). Although usage measured surgical demand; classic utilization and under- and overutilization proved to be measures that indicated the efficiency of block utilization; that is to say, when under- and overutilization are expressed as fractions of total utilization, the resultant value may be used to compare blocks of varied size on the same scale. We compared percentages of under- and overutilization among subspecialties using three-dimensional box plots to identify which subspecialties used their block time most efficiently. In addition, to identify opportunities for cost savings, we compared absolute costs of budgeted utilization and over- and underutilization among surgical subspecialties using three-dimensional box plots. In the next section, we discuss how usage, overutilization and underutilization can be used for capacity planning of subspecialty surgical blocks.

Minimal Cost Analysis Model

We used an MCA that minimized the cost of under- and overutilization to allot block time to surgical subspecialties. As a general rule, the block-specific cost of overutilization increased with usage while the cost of underutilization decreased. The under- and overutilization curves intersected at the minimal cost point, the point where the sum of costs were minimized. The model (see Appendix, equation 5, for a more detailed explanation) used to estimate the amount of time that must be allocated to the ith block of ORs to minimize the average cost of operations is the value of $B_i = B_i^*$ such that

$$P[X_i \le B_i^*] = \frac{C_o^i}{C_o^i + C_u^i} \quad \text{or} \quad P[X_i \le B_i^*] = \frac{C_o^i/C_u^i}{1 + C_o^i/C_u^i}$$

where X_i is the total time used in the ith block, B_i is the time at which the budget for the ith OR block ends, and C_o^i and C_u^i are the costs per unit of time of overutilizing and underutilizing the ith block, respectively.

As can be seen from this equation, it is not necessary to know absolute costs, only relative costs. When modeling the expected costs, the percentile of surgical demand distributed to each side of the minimal cost point may be predicted from the ratio of the costs of overutilization to underutilization; that is to say, cost ratios of one, two, and three correspond with the fiftieth, sixty-sixth, and seventy-fifth percentiles of the probability distribution, which describes daily surgical demand. When, for example, overtime is twice as expensive as regular time, costs will be minimized when underutilization represents two thirds of the area under the probability distribution function and overutilization represents one third.

Block-specific daily surgical demand was modeled by one of four probability distributions. Aggregate usage (surgical demand) from each of the 10 subspecialty blocks was fit to each of the models (normal, Weibull, gamma, or log-normal) for each day of the week. We tested each of the fitted distributions with a Kolmogorov-Smirnov test for goodness of fit and retained the best fit model for each surgical subspecialty block-day. By solving the block-specific best-fit model for the appropriate ratio of costs, we predicted the level of surgical demand most likely to minimize the costs of under- and overutilization. Thus, we predicted the block-specific surgical time allotment most likely to cater to the expected surgical demand while minimizing the cost of operating the block.

Predicted Savings from the Model

To determine block-specific opportunities for cost savings inherent in the MCA model solution, we computed actual operation costs and subtracted from these the costs expected if the MCA time allotments were to be implemented for each subspecialty block. Actual costs of operation were computed as the sum of the cost of the actual block allocation plus the measured cost of overutilization. Actual costs and MCA budgets were calculated using overtime to regular time cost ratios of one, two, and three. Potential savings were expressed as percentages of the corresponding actual costs of operation. For these analyses, we assumed that (1) all ORs were independent and interchangeable within blocks and that the blocks were different; (2) the costs of an OR was estimated as $10/min; (3) all 18 ORs were budgeted for 8 h/day, with the exception of Wednesdays when 7 h was budgeted. If the reader prefers, by adjusting the decimal one place to the left, the reader may evaluate the predicted budget savings in units of time (minutes) rather than dollars.

Statistical Analysis

Block-specific average utilization was calculated as the aggregate sum of OR time used for surgery divided by the corresponding aggregate sum of budgeted block time. Block-specific surgical usage patterns were fit to the appropriate distribution from among the normal, log-normal, Weibull and gamma distributions using Statgraphics (Statistical Graphics Corporation, Rockville, MD)[12] and the goodness of distributional fits were tested using one-sample Kolmogorov-Smirnov tests.

Results

The data consisted of 58,251 computerized records of surgical cases consisting of 5,122 different CPT-coded procedures, of which 3,166 procedures occurred two or more times. Each CPT code had 1-1,746 cases assigned. We analyzed data from 10 subspecialty surgical blocks for 1,591 weekdays or 328 weeks with from 9-18 ORs daily. To abbreviate our reporting, we summarize results for all 10 subspecialties but reported detailed results from only three representative blocks of varying size: cystoscopy, gynecology, and cardiothoracic (blocks that consisted of one, two, and three ORs, respectively).

Utilization of Subspecialty Blocks

To study the relative utilization of block times, we compared various surgical subspecialties graphically us-

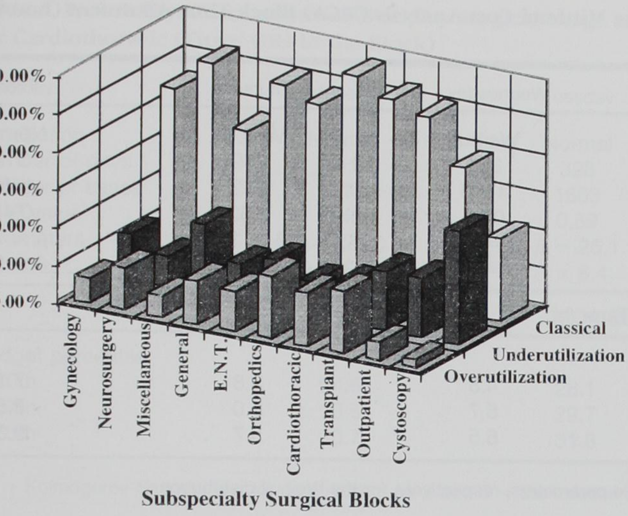

Fig. 1. Comparisons of average classic utilization, underutilization, and overutilization for Tuesdays for each of 10 surgical subspecialty blocks.

ing three-dimensional box plots. Classic, under- and overutilization were normalized measures of the *efficiency* of block time management and usage, independent of the size and absolute operational costs of the blocks. They are useful measures, therefore, because heterogeneous blocks of varying size and subspecialty may be compared one to another on a given day; alternately similar subspecialty blocks may be compared from one day to the next.

Average daily classic utilization of all the subspecialty blocks in aggregate ranged from 44–121% (cystoscopy and orthopedics, respectively) per day. Classic utilization for single-OR subspecialty blocks ranged from 44–113% (for cystoscopy and neurosurgery) whereas classic utilization for three-OR blocks ranged from 69–107% (orthopedics and cardiothoracic surgery) (see fig. 1). Average daily overutilization ranged from 4.4–49% (cystoscopy and transplantation), whereas average daily underutilization ranged from 15.9–60.3% (neurosurgery and cystoscopy). Cystoscopy had the greatest percentage underutilization and least overutilization and was therefore least in need of additional block time. Conversely, orthopedics used its block time most efficiently with greatest overutilization and least underutilization (fig. 1) and would therefore benefit from allocation of additional block time.

To compare absolute operational costs among subspecialty blocks, we compared budgeted costs and the costs of under- and overutilization graphically among the 10 surgical subspecialties (fig. 2). These comparisons of absolute costs revealed differences among subspecialty blocks of varying size. The outpatient surgery block (three ORs) had the highest cost of underutilization; more than cystoscopy, which although least efficient, was a block composed of only one OR. Cardiothoracic (three ORs) had the highest cost of overutilization, more even than orthopedics, which had two ORs. Block operational costs may also be compared across time (varying days of the week) using similar displays to compare absolute costs.

Minimal Cost Analysis Model

We used an MCA model to perform capacity planning (allocation of subspecialty block time budgets) for various surgical subspecialties based on historical patterns of surgical demand. Before applying the MCA model, probability distributions were fitted to the historical patterns of surgical demand for each surgical subspecialty. Using the ratio of regular time to overtime costs for each block, block time budgets were then allocated, which minimized the costs of under- and overutilization (MCA block time allocations).

Surgical demand (usage data) from 6 of 10 surgical subspecialty blocks (932 of 50 block-days) best fitted normal distributions, whereas data from the other 18 block-days fitted Weibull distributions (see examples tables 1–3). Although these 18 block-days also fitted normal distributions, they were better fit by Weibull distributions (Weibull is a skewed probability distribution function often used in engineering applications). In table 1, for example, we illustrated the fitting of probability

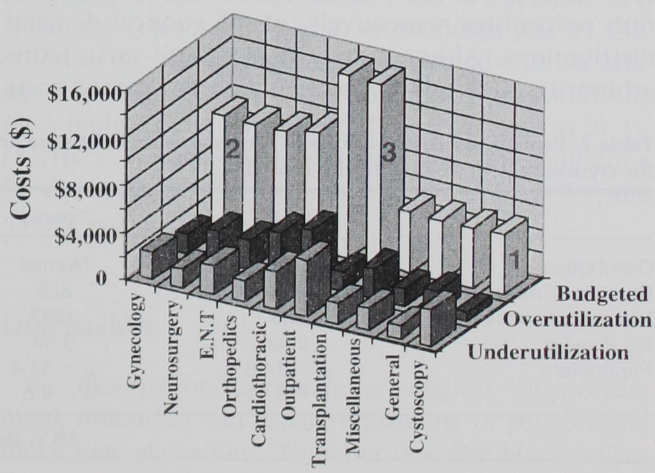

Fig. 2. Comparison of budgeted costs, underutilization, and overutilization for each of 10 subspecialty blocks for Tuesdays. Blocks are budgeted for either one, two, or three operating rooms.

Table 1. Probability Distributions of Weekday Surgical Usage and the Minimal Cost Analysis (MCA) Block Time Allotment (hours) for Cystoscopy (One OR in the Block)

	Monday	Tuesday	Wednesday	Thursday	Friday
Distribution	Weibull	Weibull	Weibull	Weibull	Normal
Number of days	289	303	291	269	312
Number of cases	1411	970	1113	942	1584
KS *P* value	0.94	0.55	0.83	0.62	0.45
Parameters	$\hat{\alpha} = 2.0$	$\hat{\alpha} = 1.5$	$\hat{\alpha} = 1.8$	$\hat{\alpha} = 1.7$	$\hat{\mu} = 7.0$
	$\hat{\beta} = 7.0$	$\hat{\beta} = 4.5$	$\hat{\beta} = 5.5$	$\hat{\beta} = 4.7$	$\hat{\sigma} = 3.4$
			MCA Block Time (h)		
Budget percentile					
50th	5.8	3.5	4.5	3.8	7.1
67th	7.3	4.8	5.7	5.0	8.5
75th	8.2	5.6	6.5	5.7	9.3

KS = Kolmogorov-Smirnov test for goodness of fit; $\hat{\alpha}$ and $\hat{\beta}$ the location and scale parameters, respectively, for the Weibull distribution.

distributions to the aggregate daily usage data for each weekday. A Weibull distribution with location parameter 2.0 and scale parameter 7.0 best fitted the data from 289 Mondays (1,411 surgical cases). The Kolmogorov-Smirnov test indicated the Weibull distribution fitted this aggregate data with $P = 0.94$.

Capacity planning using an MCA model was performed using the appropriate fitted probability distributions to estimate subspecialty block time allotments. Because underutilization is costed as regular time and overutilization is costed as overtime, cost ratios of over- to underutilization of one, two, and three were used to estimate MCA allotments corresponding to the fiftieth, sixty-seventh, and seventy-fifth percentiles respectively, of the surgical demand distributions. Although we chose these cost ratios arbitrarily, it should be noted that any ratio of costs could be applied to the model without loss of generalizability. For a specific example, in table 1, the block time allotments most likely to minimize the costs of under- and overutilization for the cystoscopy block on Mondays (based on historical patterns of demand) are 5.8, 7.3, and 8.2 h for overtime to regular time ratios of one, two, and three, respectively. Capacity planning estimates for single-suite subspecialty blocks ranged from 3.5 h to a high of 11.5 h (cystoscopy and general surgery, respectively) per day. In comparison, subspecialty blocks with three suites varied from 17.2 h to a high of 31.8 h (outpatient and cardiothoracic surgery, respectively). An MCA time budget determination is illustrated graphically for the gynecology block (fig. 3) in which the costs of under- and overutilization are plotted *versus* the subspecialty block time used (surgical demand).

Table 2. Probability Distributions of Weekday Surgical Usage and the Minimal Cost Analysis (MCA) Block Time Allotment (hours) for Gynecology (Two ORs in the Block)

	Monday	Tuesday	Wednesday	Thursday	Friday
Distribution	Normal	Normal	Normal	Normal	Normal
Number of days	300	328	326	322	313
Number of cases	939	1387	1081	1310	1066
KS *P* value	0.82	0.09	0.92	0.98	0.63
Parameters	$\hat{\mu} = 14.6$	$\hat{\mu} = 14.4$	$\hat{\mu} = 14.1$	$\hat{\mu} = 14.5$	$\hat{\mu} = 13.1$
	$\hat{\sigma} = 5.1$	$\hat{\sigma} = 4.6$	$\hat{\sigma} = 5.4$	$\hat{\sigma} = 4.5$	$\hat{\sigma} = 5.2$
			MCA Block Time (h)		
Budget percentile					
50th	14.6	14.4	14.1	14.5	13.1
67th	16.8	16.4	16.5	16.4	15.4
75th	18.1	17.5	17.8	17.5	16.6

KS = Kolmogorov-Smirnov test for goodness of fit; $\hat{\mu}$ and $\hat{\sigma}$ = the location and scale parameters, respectively, for the Normal distribution.

Table 3. Probability Distributions of Weekday Surgical Usage and the Minimal Cost Analysis (MCA) Block Time Allotment (hours) for Cardiothoracic (Three ORs in the Block)

Weekday	Monday	Tuesday	Wednesday	Thursday	Friday
Distribution	Normal	Normal	Normal	Normal	Normal
Number of days	311	328	328	325	327
Number of cases	1370	1603	1413	1573	1437
KS *P* value	0.40	0.59	0.99	0.77	0.90
Parameters	$\hat{\mu}$ = 24.6	$\hat{\mu}$ = 26.1	$\hat{\mu}$ = 24.9	$\hat{\mu}$ = 25.7	$\hat{\mu}$ = 24.0
	$\hat{\sigma}$ = 8.9	$\hat{\sigma}$ = 8.4	$\hat{\sigma}$ = 8.7	$\hat{\sigma}$ = 8.2	$\hat{\sigma}$ = 9.1
			MCA Block Time (h)		
Budget percentile					
50th	24.6	26.1	24.9	25.7	24.0
67th	28.5	29.7	28.7	29.3	27.9
75th	30.7	31.8	30.8	31.3	30.1

KS = Kolmogorov-Smirnov test for goodness of fit; $\hat{\mu}$ and $\hat{\sigma}$ = the location and scale parameters, respectively, for the Normal distribution.

Predicted Savings from the Model

To illustrate the potential for savings if the MCA block time budgets were to be implemented, we compared actual operational costs with estimated MCA budget costs for each of the subspecialty blocks. The estimated MCA block time costs were subtracted from the actual historical costs of operations (the cost of budgeted block time plus the costs of overutilization) and the potential savings were expressed as a percentage of actual operational costs. To estimate costs, we assumed the cost of a single surgical suite to be $10.00/min, from which we estimated the budgeted cost of operating it for 8 h as $4,800. It follows that the cost of operating two or three suite blocks would be $9,600 or $14,400/day, respectively. For the purposes of these estimates we assumed that the cost of regular and overtime were equal. If, however, because it is often the case, the cost of overutilization exceeds the cost of underutilization by some ratio, then the actual costs would be even greater.

Actual costs of daily operation ranged from $5,532 to a high of $20,559 (cystoscopy and cardiothoracic blocks, respectively, see examples tables 4–6). Potential savings from using the MCA budgets ranged from 1.2 (general surgery on Mondays, cardiothoracic surgery on Tuesdays) to 47.2% for cystoscopy on Thursdays. In table 4, for example, the average actual costs of operation of a single OR (cystoscopy block) on Mondays was $5,532, whereas the MCA budget estimate would cost on average $4,365 on Mondays. The potential savings were the MCA budget to be implemented was estimated as 21.1% ($1,167). Average classic and over- and underutilization for the cystoscopy block on Mondays was 64.2, 7.4, and 43.2%, respectively.

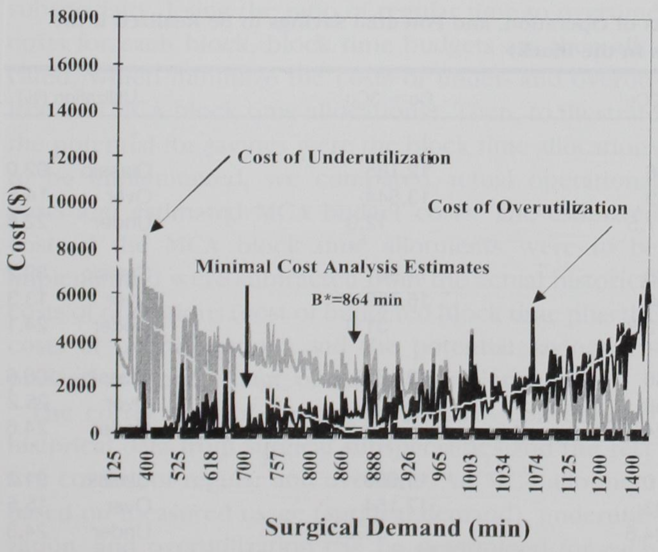

Fig. 3. A minimal cost analysis (MCA) model for capacity planning of the gynecology subspecialty block on Tuesdays. Plot of operating room time used (historical surgical demand) *versus* the costs of actual underutilization and overutilization and the average costs of under- and overutilization estimated using the MCA strategy. The MCA budget estimate (B*) is 864 min when the ratio of overtime to regular time costs is 1.

Discussion

We describe measurement of surgical subspecialty block utilization and capacity planning of subspecialty block time allocations. To better describe block utilization we define new terms underutilization and overutilization and illustrate how these measures relate to budgeted and classic measures of utilization. Classic and under- and overutilization are useful measures of the efficiency of management and use of the subspecialty

Table 4. Minimal Cost Analysis (MCA) Budget Estimates, Actual Costs of Operation, and Potential Savings to Be Realized if the MCA Time Allotments Were Implemented for Cystoscopy (One OR in the Block)

	Co = Cu	Co = 2Cu	Co = 3Cu	Utilization (%)	
Mondays					
MCA budget ($)	4,365	5,361	5,921	Classic	64.2
Actual cost ($)	5,532	5,964	6,397	Over	7.4
Savings (%)	21.1	10.1	7.4	Under	43.2
Tuesdays					
MCA budget ($)	2,937	3,890	4,453	Classic	44.3
Actual cost ($)	5,749	6,397	7,046	Over	4.6
Savings (%)	48.9	39.2	36.8	Under	60.3
Wednesdays					
MCA budget ($)	3,463	4,379	4,939	Classic	59.2
Actual cost ($)	5,400	6,300	7,200	Over	8.9
Savings (%)	35.9	30.5	31.4	Under	49.7
Thursdays					
MCA budget ($)	3,014	3,408	3,716	Classic	47.4
Actual cost ($)	5,847	6,594	7,341	Over	4.4
Savings (%)	48.5	48.3	49.4	Under	56.9
Fridays					
MCA budget ($)	5,053	6,026	6,229	Classic	67.8
Actual cost ($)	6,009	6,918	7,827	Over	7.5
Savings (%)	15.9	12.9	20.4	Under	39.7

Values are daily averages for one surgical suite.

Co = cost of overutilization; Cu = cost of underutilization.

blocks independent of the size and cost of block operations. Conversely, costs of budgeted, underutilization, and overutilization, are useful measures for comparison among blocks of absolute operational costs. Our methods are useful for measuring the quality of surgical schedules and assessing the effect of management decisions that alter block utilization.

We use an MCA model to perform capacity planning

Table 5. Minimal Cost Analysis (MCA) Budget Estimates, Actual Costs of Operation, and Potential Savings to Be Realized if the MCA Time Allotments Were Implemented for Gynecology (Two ORs in the Block)

	Co = Cu	Co = 2Cu	Co = 3Cu	Utilization (%)	
Mondays					
MCA budget ($)	10,036	11,456	12,185	Classic	92.0
Actual cost ($)	10,934	12,389	13,844	Over	14.6
Savings (%)	8.2	7.5	12.0	Under	22.6
Tuesdays					
MCA budget ($)	9,742	10,938	11,561	Classic	89.2
Actual cost ($)	11,961	14,360	16,759	Over	13.3
Savings (%)	18.6	23.8	31.0	Under	24.1
Wednesdays					
MCA budget ($)	9,770	11,336	12,125	Classic	100.6
Actual cost ($)	11,637	14,950	18,263	Over	25.2
Savings (%)	16.0	24.2	33.6	Under	24.6
Thursdays					
MCA budget ($)	9,749	11,010	11,680	Classic	91.2
Actual cost ($)	12,032	14,593	17,154	Over	15.5
Savings (%)	19.0	24.6	31.9	Under	24.3
Fridays					
MCA budget ($)	9,147	10,657	11,457	Classic	83.9
Actual cost ($)	12,040	14,763	17,486	Over	13.3
Savings (%)	24.0	27.8	34.5	Under	29.4

Values are daily averages for two surgical suites.

Co = cost of overutilization; Cu = cost of underutilization.

Table 6. Minimal Cost Analysis (MCA) Budget Estimates, Actual Costs of Operation, and Potential Savings to Be Realized if the MCA Time Allotments Were Implemented for Cardiothoracic (Three ORs in the Block)

	Co = Cu	Co = 2Cu	Co = 3Cu	Utilization (%)	
Mondays					
MCA budget ($)	17,997	20,577	21,776	Classic	105.4
Actual cost ($)	19,524	23,912	28,300	Over	28.3
Savings (%)	7.8	13.9	23.1	Under	22.9
Tuesdays					
MCA budget ($)	18,786	21,265	22,578	Classic	107.1
Actual cost ($)	19,911	24,406	28,901	Over	28.5
Savings (%)	5.6	12.9	21.9	Under	21.4
Wednesdays					
MCA budget ($)	18,432	21,101	22,487	Classic	103.9
Actual cost ($)	20,559	25,751	30,942	Over	32.6
Savings (%)	10.3	18.1	27.3	Under	28.7
Thursdays					
MCA budget ($)	18,681	21,049	22,312	Classic	106.2
Actual cost ($)	20,174	24,863	29,551	Over	29.8
Savings (%)	7.4	15.3	24.5	Under	23.6
Fridays					
MCA budget ($)	17,989	20,828	22,293	Classic	102.1
Actual cost ($)	19,437	23,679	27,921	Over	26.9
Savings (%)	7.5	12.0	20.2	Under	24.8

Values are daily averages for three surgical suites.
Co = cost of overutilization; Cu = cost of underutilization.

for various surgical subspecialties based on historical patterns of surgical demand. Before applying the MCA model, probability distributions must be fitted to the historical patterns of surgical demand for each surgical subspecialty. Using the ratio of regular time to overtime costs for each block, block time budgets are then allocated, which minimize the costs of under- and overutilization (MCA block time allocations). Then, to illustrate the potential for savings were the block time allocations to be implemented, we compared actual operational costs and estimated MCA budget costs. The estimated costs if the MCA block time allotments were to be implemented were subtracted from the actual historical costs of operations (cost of budgeted block time plus the costs of overutilization) and the potential savings expressed as a percentage of actual operational costs.

The correct use of our model requires collection of historical data from surgical subspecialties and the relative costing of regular and overtime. An MCA allotment based on measured usage (surgical demand), underutilization, and overutilization can be determined for each subspecialty block. Managers may then determine (through additional analyses) whether it is more desirable to increase the duration of the budgeted work day, to build additional suites,[13] or to reassign surgical suites from underutilized to overutilized blocks. We anticipate improved prediction of surgical capacity when a segmented approach to the analysis is undertaken.

The surgical demand–variable resource allocation model is common in the private enterprise, American healthcare system. In this competitive system, blocks of ORs are scheduled unconstrained by limits on additional resources; new cases are scheduled into each block on a first-come, first-serve basis; and surgical demand is determined by the market.[7] Business can be lost if cases are deferred, therefore operating capacity must be kept high enough to satisfy demand. Conversely, the ORs are cost centers that need to run efficiently or they threaten the financial health of the institution; therefore, capacity must be kept low. This American scenario differs from common Canadian and British models (and some American) in which subspecialty time budgets are fixed and a scheduling queue is modified to meet elective needs plus emergencies, rather than altering the surgical time budget to meet surgical demands.[14]

Our solution to the minimum cost model assumed that the surgical demand was relatively static over time. This is rarely true, however, and in practice the solution must be reevaluated periodically. The model assumptions for different blocks may have to be revised at varying intervals because they could have different seasonalities (cyclical patterns in surgical demand), and the revision period may depend on the duration of the seasonality. Also, distributional assumptions may change as surgical specialists arrive at or depart from the medical staff.

Our data may not reflect average surgical demand and typical practice patterns. The data were collected from an academic teaching hospital and may be biased by varied, new, and specialized procedures, together with limitations inherent in training physicians and personnel. Also, because the data are sampled from work actually performed, they have been subjected to the cutoff rules in effect for scheduling at the time the data were acquired, and, hence, may not represent the entire universe of surgical demand at the hospital. We have also assumed that capacity can be adjusted independently as a continuous variable for each day of the week, but this may be difficult to achieve in practice, even if data collection is automated.

The capacity planning solution provided herein should be helpful to surgical managers trying to anticipate future demand and the need for surgical capacity. They may wish to maximize revenue for the hospital by recognizing patterns of unmet and changing demand and adjust capacity accordingly. Similar methods also could be applied to other surgical areas, such as the postanesthesia care units or outpatient clinics. Although these retrospective data do not allow us to address this issue, the methodology displayed herein is still applicable.

There are two sources of potential savings inherent in our measures of utilization. First, there are some obligate normal sources of imperfect utilization. Neither underutilization nor overutilization, which include turnover time and surgical emergencies respectively, can be totally eliminated. The best we can expect is to quantitate them and measure the effect of management decisions aimed at reducing them. A second and subsequent savings is inherent in implementation of the MCA budgets. These MCA budgets are based on historical patterns of underutilization and overutilization and do not require assumptions of improved turnover or reduced emergency surgeries to offer savings. These savings, rather, are inherent in improved matching of surgical supply and surgical demand and are related to reduced overbooking or underbooking of surgical schedules. The total potential for savings, therefore, is the sum of savings from the MCA budgets plus those inherent in improved efficiencies in surgical processes.

Our model evaluates the use of OR time as a function of underutilization and overutilization and reveals the potential savings if either or both could be eliminated. We showed that these new measures can be used to compare efficiencies and costs among surgical subspecialties and to perform capacity planning (optimizing subspecialty surgical block time allotments). Our model is also useful for measuring the quality of surgical schedules and accurately gauging the effect of management decisions that alter OR utilization.

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Appendix

Utilization of Subspecialty Blocks

To develop a model of OR utilization, it is necessary to distinguish between utilization and usage. *Utilization* is a function of OR time, used and budgeted, whereas *usage* is the total amount of time the ORs are used, *i.e.*, the surgical demand. Therefore, *classic utilization* (ρ) is a relative measure given by the ratio of usage to the budgeted time, whereas usage is an absolute measure. We propose two new relative measures, overutilization (ρ_o) and underutilization (ρ_u), that better describe the functioning of surgical services.

The notation used is given below. In this article, an *operating room* is a room in which surgery is performed, and a subspecialty surgical *block* is a group of ORs in which equipment and personnel are interchangeable with each other, but not necessarily with ORs outside the block. Let

s_p^i: starting time of the pth procedure performed in the ith block;

x_p^i: ending time of the pth procedure performed in the ith block, and $s_p^i < x_p^i$, ;

$\phi_p^i(x)$: probability density function of $x_p^i - s_p^i$, ;

$\phi^i(x)$: probability density function of the used time in the ith block, *i.e.*, $\sum_p (x_p^i - s_p^i)$. In general, it is given by the convolution of the probability distributions of the individual procedure durations;

B_i: time at which the budget for the ith OR block ends. We assume without loss of generality that the budgeted day starts at time 0 for all the blocks;

P_i^+: set of procedures scheduled in the ith block, with starting and ending times outside the budgeted day and that do not use budgeted time, *i.e.*,

$$P_i^+ = \{p \mid x_p^i \le 0 \quad \text{or} \quad s_p^i \ge B_i\}.$$

P_i^-: set of procedures scheduled in the ith block with starting or ending times, or both, within the budgeted day or that use budgeted time, *i.e.*,

$$P_i^- = \{p \mid 0 \le s_p^i < B_i \quad \text{and} \quad x_p^i \ge B_i\} \cup \{p \mid s_p^i < 0 \quad \text{and} \quad 0 \le x_p^i \le B_i\}$$
$$\cup \{p \mid 0 \le s_p^i < x_p^i \le B_i\} \cup \{p \mid s_p^i < 0 \quad \text{and} \quad x_p^i > B_i\}$$

where ∪ represents the union of sets.

X_i: total time used in the ith block;

X_o^i: total time that the ith block is overutilized;

X_u^i: total time that the ith block is underutilized;

C_o^i: cost per unit of time of overutilizing the ith block;

C_u^i: cost per unit of time of underutilizing the ith block.

Overutilization of the ith block of ORs (ρ_o^i) is the ratio of time used by cases during nonbudgeted hours to the total block time budgeted (B_i). The numerator of this ratio is the sum of procedure times for procedures that do not use budgeted time, *i.e.*, $\sum_{p \in P_i^+} (x_p^i - s_p^i)$, and the amount of time used outside the budget by those procedures that overlap the budget period. If the procedure is started before the beginning of the budgeted time, and it ends during the budgeted period, the overutilization is given by: $(-s_p^i)$. Recall that the beginning of the budgeted time was assumed to be 0; if the procedure is started during the budgeted period and finished after the end of the budgeted time, the overutilization is given by: $(x_p^i - B_i)$; and if the starting and ending times span the entire budgeted period, then the overutilization is given by: $(x_p^i - s_p^i - B_i)$. Thus, the overutilization of the ith block is given by:

$$\rho_o^i(x^i) = \frac{1}{B_i}\left[\sum_{p \in P_i^-} (\max\{0 - s_p^i, 0\} + \max\{x_p^i - B_i, 0\}) + \sum_{p \in P_i^+} (x_p^i - s_p^i)\right] = \frac{X_o^i}{B_i}. \quad (1)$$

Similarly, the *underutilization* of the ith OR block (ρ_u^i) is given by the ratio of the total amount of budgeted time not used and the total amount budgeted (B_i):

$$\rho_u^i(x^i) \equiv \frac{1}{B_i}\left[\max\left\{\left(B_i - \sum_{p \in P_i^-} (x_p^i - s_p^i)\right), 0\right\}\right] = \frac{X_u^i}{B_i}. \quad (2)$$

As shown before, classic utilization for the ith block can be defined as the total time the block is used divided by the block time budget and can be shown to be equal to

$$E[\rho^i(x)] = 1 - E[\rho_u^i(x) - \rho_o^i(x)] \quad (3)$$

which does not accurately detect inefficiencies that result in under- and overutilization of the block time.

Minimal Cost Analysis Model

To minimize costs, we developed a model applicable to capacity planning for surgical subspecialty block times. The minimum cost solution can be determined by knowing only the distribution of the X_i, the total time used in ith block, and the relative hourly cost of under- and overutilization. This is true regardless of how the distribution of the X_i is determined. Because these blocks can be independently budgeted, they can be optimized separately or together. Let us assume that there are n noninterchangeable blocks of ORs and the ORs within each block are interchangeable. For each of these blocks we can determine the optimum amount of time (B_i) that they should be budgeted to minimize the total expected cost.

Let $C(x_i)$ be the total cost associated with using the blocks of ORs 1, 2, . . ., n, x_1, x_2, . . . , x_n time units, respectively. This cost can be written as the sum of the costs of overutilization given by $\sum_i C_o^i[\max\{x_i - B_i, 0\}]$, and as the costs of underutilization given by $\sum_i C_u^i[\max\{B_i - x_i, 0\}]$. Thus, the total cost is given by

$$C(x_i) = C_o^i[\max\{x_i - B_i, 0\}] + C_u^i[\max\{B_i - x_i, 0\}] \quad (4)$$

The amount of time that the ith block of ORs must be allocated to minimize the average cost is the value of $B_i = B_i^*$, such that

$$P[X_i \le B_i^*] = \frac{C_o^i}{C_o^i + C_u^i} \quad \text{or} \quad P[X_i \le B_i^*] = \frac{C_o^i/C_u^i}{1 + C_o^i/C_u^i}. \quad (5)$$

Simply stated, $B_i = B_i^*$ is the $100(C_o^i/C_u^i)(1 + C_o^i/C_u^i)^{-1}$ percentile of the probability distribution of X_i. Thus, if, for example, the cost of overutilization exceeds underutilization by ratios of 1, 2, or 3 (C_o^i/C_u^i = 1, 2 or 3), then $B_i = B_i^*$ is the fiftieth, sixty-seventh and seventy-fifth percentiles, respectively. Note, that to perform the analysis, it is not necessary to know the actual cost of overutilization and underutilization, just their relative cost, *i.e.*, C_o^i/C_u^i. The amount of time that this model allocates to each block, $B_i = B_i^*$, depends on the distribution of surgical demand.