How to Release Allocated Operating Room Time to Increase Efficiency: Predicting Which Surgical Service Will Have the Most Underutilized Operating Room Time

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At many facilities, surgeons and patients choose the day of surgery, cases are not turned away, and staffing is adjusted to maximize operating room (OR) efficiency. If a surgical service has already filled its allocated OR time, but has an additional case to schedule, then OR efficiency is increased by scheduling the new case into the OR time of a different service with much underutilized OR time. The latter service is said to be "releasing" its allocated OR time. In this study, we analyzed 3 years of scheduling data from a medium-sized and a large surgical suite. Theoretically, the service that should have its OR time released is the service expected to have the most underutilized OR time on the day of surgery (i.e., any future cases that may be scheduled into that service's time also need to be factored in). However, we show that OR efficiency is only slightly less when the service whose time is released is the service that has the most allocated but unscheduled (i.e., unfilled) OR time at the moment the new case is scheduled. In contrast, compromising by releasing the OR time of a service other than the one with the most allocated but unscheduled OR time markedly reduces OR efficiency. OR managers can use these results when releasing allocated OR time.

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At many hospitals and freestanding surgical centers, surgeons and patients choose the day of surgery, cases are not turned away, and anesthesia and nursing staffing are adjusted to maximize the efficiency of use of operating room (OR) time (1–5). This "open scheduling" system is sometimes referred to as "Any Workday," in that the surgeons can choose Any Workday for a case. Typically, in the United States, even if a service has filled its allocated OR time, hospital administrators encourage surgeons to do more cases. The surgeons may get additional cases onto the schedule by calling them "add-on" or "urgent."

Previously, we studied how such facilities should schedule cases to maximize OR efficiency (3). By far the most important step is to allocate OR time appropriately. Then, only rarely should services encounter the situation wherein their allocated OR time is full and, yet, they have another case to schedule (1,4). Still, when this event happens, OR efficiency is enhanced by scheduling the case into the OR time of the service expected to have the most underutilized OR time on the day of surgery, assuming availability of the surgeon, equipment, etc. (3).

The service that is "releasing" its allocated OR time for that case is not losing access to OR time, meaning that its surgeons can continue to book cases for that workday (1–2,4). If the service was to have another case, it could be scheduled into the remaining portion of its allocated OR time or into other available OR time. Still, that service should generally not be inconvenienced, because that service should have been chosen to have its OR time released because the probability was high that the service would not schedule additional cases.

Surgical services fill their allocated OR time at different rates. For example, at the University of Iowa, the median time between when a patient is scheduled for surgery and the actual day of surgery ranges from 2 to 27 days depending on the subspecialty. Whereas outpatient ophthalmology may schedule cases weeks before the day of surgery, cardiothoracic surgery may

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book cases a few days before the day of surgery. Consequently, to maximize OR efficiency, allocated OR time cannot be released for all services the same number of prespecified days before surgery (3). Rather, what is necessary is to predict, at the moment that a case is scheduled, which surgical service will have the most underutilized OR time in the future on the day of surgery (3). In this paper, we study how to do that.

Methods

This study used all the elective cases performed at two surgical suites between July 1, 1998, and June 30, 2001 (Table 1). They are medium and large suites according to nationwide standards (6). We did all the analyses in this study separately for the two surgical suites.

OR time was allocated in the manner that maximizes OR efficiency, quantified using underutilized and overutilized hours of OR time (1,2). For example, if regularly scheduled OR hours are 7 AM to 3 PM, and the last case of the day ends at 1 PM, then there are 2 underutilized OR hours (1,2). In contrast, if the last case of the day ends at 5:30 PM, then there are 2.5 overutilized OR hours.

The inefficiency of use of OR time is measured by taking the sum of two products: "the hours of underutilized OR time × the cost per hour of underutilized OR time" and "the hours of overutilized OR time × the cost per hour of overutilized OR time" (1,2).

A service's daily OR workload was defined as the service's total hours of elective cases including turnover times for that day. Each service's OR workload was calculated for each workday of the 3-year period. The best OR allocation to maximize OR efficiency for each combination of the day of the week and service was obtained from these OR workload values using previously published methods (Table 1) (1,2).

Parameter values chosen for these calculations were (i) a relative cost of overutilized to underutilized OR time of 1.75 and (ii) a regularly scheduled workday of 8 hours. Briefly, the expected efficiency of use of OR time was obtained for each day of the week and service using 0 allocated hours (0 ORs), 8 allocated hours (1 OR), 16 allocated hours (2 ORs), and so forth. The optimal OR allocation was the number of 8-hour ORs yielding the highest expected efficiency of use of OR time (1–5).

To describe characteristics of the OR allocations, we calculated the percentage of days for which at least one service had enough underutilized OR time for a new case to be done in regularly scheduled OR hours. The duration of these hypothetical new cases were 1, 2, or 3 hours. Such cases are short, average, and long by national standards. The new cases were "imaginary," whereas the available OR times were "real" data. We calculated the difference in these percentages between the medium and the large surgical suites. We obtained 95% confidence intervals for the differences (7) (StatXact-4, Cytel Software Corporation, Cambridge, MA).

Rule #1 to schedule the new case: Release the OR time of the service that has the most *expected* underutilized OR time on the day of surgery.

Rule #1 maximizes OR efficiency (3). In practice, the OR information system would perform the forecasting, and provide a recommendation to the OR scheduler.

We determined "the service that has the most expected underutilized OR time" using the following method. The expected hours of underutilized OR time for a service are the hours allocated to the service for that day of the week, less any hours already scheduled, and less the expected hours that the service will schedule in the days remaining until surgery (8). The expected hours are the expected future bookings of cases. These expected future bookings were estimated by taking the mean of cases and turnover times scheduled by that service between those days of the week over the preceding 48 weeks (9).

For example, to estimate the expected future bookings for Service D on Mondays using data from the preceding Thursday, we used the mean difference, over the preceding 48 weeks, of (i) the total hours of elective cases including turnover times of Service D on Monday and (ii) the total hours of cases, including turnover times, scheduled for Service D by the end of the preceding Thursday. Thus, as in a system used by airlines, the expected future bookings of cases was based on the surgical service (i.e., flight number), the day of the week, and number of days before surgery (i.e., number of days before departure), and not on the hours of cases already scheduled (i.e., current seat bookings) (8).

Rule #2 to schedule the new case: Release the OR time of the surgical service that has the largest difference between allocated and scheduled OR time at the moment the new case is scheduled.

This rule is convenient, but is not optimal like Rule #1 above. In practice, for small and medium suites, the scheduler would simply look at the time remaining in each OR to determine the appropriate service to have its OR time released. For large suites, it may be convenient for the OR information system to perform the arithmetic for the scheduler.

For example, suppose that 6 services have each been allocated 8 hours of OR time. The total hours of elective cases including turnover times previously scheduled into each service's OR time were 4, 7, 5, 6, 5, and 8 hours. The service with fully scheduled OR time has a new case. The case would be scheduled into the OR time of the service that has previously scheduled 4 hours of cases.

Table 1. Number of 8-Hour ORs Allocated to Each Surgical Service[a]

Suite	Service	Monday	Tuesday	Wednesday	Thursday	Friday
Medium	B	0	0	1	0	1
	F	0	0	0	0	1
	D	1	0	1	0	1
	E	1	2	2	2	1
	H	1	1	1	2	1
	G	1	2	0	0	1
	I	0	0	0	0	1
	Overall	4	5	5	4	7
Large	A	2	3	2	3	2
	B	0	1	0	1	0
	F	5	5	5	5	5
	D	2	1	1	1	1
	C	2	2	3	2	3
	E	1	0	1	1	1
	H	4	4	4	3	4
	G	2	2	4	3	3
	I	2	2	2	2	1
	Overall	20	20	22	21	20

[a] CalculatOR (MDA Ltd., Jenkintown, PA) was used to create the OR allocations, using the previously published methods (1,2). Services with small volumes on all days of the week (e.g., internal medicine bone marrow harvesting) are not listed. Services with 0 OR listed schedule into open first-come first-served OR time on that day of the week (2). Such service and day combinations were not included in analyses.

Rule #3 to schedule the new case: Release the OR time of the service with the second largest difference between allocated and scheduled OR time.

We tested this rule, because constraints or restrictions on the availability of staff or equipment may prevent the surgical service with the largest difference from getting the new case.

To compare the effects on OR efficiency of Rule #1 and Rule #2, the $n = 514$ workdays. For Rule #1, we applied the first 48 weeks of data to the 49th week, the 2nd through 49th week of data to the 50th week, and so forth. When there was an intervening holiday, fewer days of data were used in the forecasting to maintain the same sample size. Thus, $n = 514$ workdays, because 514 = (754 workdays during the 3 years) − (48 weeks × 5 days per week).

To compare Rule #2 and Rule #3, the $n = 754$ workdays, because no forecasting was needed.

OR time is released when a service has filled its appropriately allocated OR time and has another case to schedule (3). The number of days before the day of surgery when each service filled its allocated OR time was (median ± quartile deviation) 3 ± 3 ($n = 928$) for the medium suite and 1 ± 2 ($n = 2{,}337$) for the large suite. We studied new cases scheduled on the morning of the day before surgery (shortest possible) and 5 days before the day of surgery (longest reasonable time that we could study using the data). In that almost all cases are scheduled on workdays, we called 5 days before the day of surgery as "one week."

The end-points of the comparisons of the three rules were differences in OR efficiency. A few days before the day of surgery and on the day of surgery, the direct incremental cost per hour of underutilized OR time is zero, because staff have been scheduled (3). Since services fill their allocated OR time within a few days before the day of surgery, the underutilized OR time does not affect calculated OR efficiency. Thus, we compared the rules based on mean pair-wise differences in overutilized OR time.

The fewer the hours of overutilized OR time, the greater the OR efficiency (1,3). Since many facilities schedule cases in 15-minute increments, we considered differences in overutilized OR time of < 15 minutes, 15 to 30 minutes, and > 30 minutes to be "small," "moderate," and "large," respectively. We calculated 95% confidence intervals for the true mean pair-wise differences by using Student's *t*-distribution.

Results

The OR time released could be OR time that was allocated to the service with the largest current difference between allocated and scheduled OR time, rather than OR time originally allocated to the service expected to have the most underutilized OR time on the day of surgery (Table 2). For the medium surgical suite, this did not result in statistically significant differences in overutilized OR time (Table 2). For the large surgical suite, the differences were significant, but small.

The OR time released could be OR time that was allocated to the service with the second most, rather than the most, allocated but unscheduled OR time. Then, overutilized OR time was significantly increased, under all conditions (Table 3). At the medium surgical suite, the differences in excess overutilized

Table 2. Scheduling a Case into the OR with the Most Allocated but Unscheduled OR Time at the Moment the Case is Scheduled Versus Scheduling the Case into the OR with the Most Expected Underutilized OR Time

Size of surgical suite	Duration of new case (h)	When new case is submitted	Excess minutes of overutilized[a] OR time (95% confidence interval, N = 514 workdays for each)
Medium	1	Day before surgery	0 (−1 to 1)
	1	Week before surgery	0 (−1 to 1)
	2	Day before surgery	0 (−1 to 2)
	2	Week before surgery	0 (−1 to 2)
	3	Day before surgery	1 (−2 to 3)
	3	Week before surgery	1 (−2 to 4)
Large	1	Day before surgery	2 (1 to 3)
	1	Week before surgery	6 (4 to 8)
	2	Day before surgery	5 (2 to 7)
	2	Week before surgery	12 (7 to 16)
	3	Day before surgery	7 (4 to 11)
	3	Week before surgery	18 (12 to 24)

[a] A few days before the day of surgery and on the day of surgery, the direct incremental cost per hour of underutilized OR time is zero (3). Thus, maximizing the efficiency of use of OR time is the same as minimizing the hours of overutilized OR time (1,3).

Table 3. Differences in Amount of Overutilized[a] OR Time Between Scheduling a Case into the OR with the Second Most, Instead of Most, Allocated but Unscheduled OR Time

Size of surgical suite	Duration of new case (h)	When new case is submitted	Excess minutes of overutilized[a] OR time (95% confidence interval, N = 754 workdays for each)
Medium	1	Day before surgery	11 (10 to 13)
	1	Week before surgery	12 (10 to 14)
	2	Day before surgery	26 (22 to 30)
	2	Week before surgery	26 (21 to 30)
	3	Day before surgery	42 (36 to 47)
	3	Week before surgery	41 (35 to 47)
Large	1	Day before surgery	6 (4 to 9)
	1	Week before surgery	5 (2 to 7)
	2	Day before surgery	14 (9 to 18)
	2	Week before surgery	10 (5 to 15)
	3	Day before surgery	22 (15 to 29)
	3	Week before surgery	17 (9 to 25)

[a] A few days before the day of surgery and on the day of surgery, the direct incremental cost per hour of underutilized OR time is zero (3). Thus, maximizing the efficiency of use of OR time is the same as minimizing the hours of overutilized OR time (1,3).

OR time were small, moderate, and large for short, average, and long duration cases, respectively. For the large surgical suite, the differences were small, small, and moderate, respectively.

To understand why results were sensitive to the size of the surgical suite, we examined the relative proportions of underutilized and overutilized OR time. Underutilized OR time is less expensive than overutilized OR time (1–4). Thus, more than half of the service and day combinations were underutilized (medium suite, 69% ± SE 1%, n = 3,007; large suite, 62% ± 1%, n = 6,183) (Table 1). Every service's mean hours of underutilized OR time exceeded its mean overutilized OR time. Overall for the medium suite, mean underutilized OR time (2.75 ± 0.06 h) exceeded mean overutilized OR time (1.07 ± 0.04 h). Overall for the large suite, mean underutilized OR time (3.98 ± 0.07 h) also exceeded mean overutilized OR time (1.71 ± 0.04 h).

Because there was more underutilized than overutilized OR time, the results of Tables 2 and 3 were

Table 4. The Medium-Sized Suite Had a Larger Percentage of Days than Did the Large Suite for Which the New Case Could Not Be Scheduled Without Producing Overutilized[a] OR Time

Duration of new case (h)	Medium surgical suite (%)	Large surgical suite (%)	Point estimate of the difference of the percentages (%)	95% confidence interval for difference of the percentages (%)
1	6.7[b]	0.0	6.6	4.7 to 8.9
2	11.3	0.1	10.9	8.4 to 13.7
3	21.5	0.1	21.4	17.5 to 24.1

[a] A few days before the day of surgery and on the day of surgery, the direct incremental cost per hour of underutilized OR time is zero (3). Thus, maximizing the efficiency of use of OR time is the same as minimizing the hours of overutilized OR time (1,3).

[b] This means that, with perfect information, 6.7% of 754 workdays did not have enough unscheduled (unfilled) OR time on the day of surgery so that a 1-h case could be added into at least one surgical service's OR time without incurring overutilized OR time.

sensitive to the size of the surgical suite. Specifically, each increase in the number of ORs in a surgical suite gave a larger probability that at least one OR would have enough open OR time that the new case could be done in what would otherwise be underutilized OR time (Table 4) (10).

For example, for the large surgical suite, there were 7 to 8 services with 15 to 20 ORs into which the new case could be scheduled (Table 1). Each of these service and day of the week combinations had a more than 50% chance of underutilized OR time. Together, the number of choices was large enough to provide a 99% success rate at finding an OR for the new case without producing overutilized OR time (Table 4).

The medium surgical suite had fewer choices of services and ORs into which to schedule the new case than did the large surgical suite (Tables 1 and 4). Thus, reducing the number of choices by one (Table 3) had a disproportionately harmful effect on OR efficiency for the medium surgical suite.

Discussion

A common problem in OR management is when and how to "release" allocated OR time to maximize OR efficiency. Specifically, when a service has filled its allocated OR time, but has another elective case to be scheduled, OR efficiency is maximized by scheduling the case into the OR time of the service expected to have the most underutilized OR time, rather than into overutilized OR time (3).

Generally, this is not the same as scheduling the case into the OR time of the service with the largest current difference between allocated and scheduled OR time, as displayed by OR information systems. Theoretically, the two methods are different because services fill their allocated OR time at different rates. Yet, we showed that, in practice, the difference in OR efficiency between the two methods is statistically insignificant or small (Table 2). Thus, when OR time is allocated appropriately, OR managers can use the latter, simpler, method, knowing that it will work well to maintain OR efficiency.

Constraints may limit the choice of ORs into which a new case can be scheduled. Some constraints are absolute (e.g., cardiac surgery cannot be done in an ophthalmology OR with a suspended microscope). Still, many OR scheduling constraints are relative (e.g., the OR manager may prefer to not schedule a case into the OR time of a service with a pugnacious surgeon). We found that releasing the OR time of the service with the second most allocated but unscheduled OR time can have a large negative effect on OR efficiency (Table 3). So, whenever possible, the OR manager should put the case into the OR time of the service with the most allocated but unscheduled OR time. This is particularly important for long ($\geq$ 3 h) cases scheduled at medium (and small) surgical suites.

Moving a case on the day of surgery can be helpful when a case is scheduled into released OR time but that OR has specialized equipment that is now needed by that OR's original service for an urgent case. Moving the case is usually an option because a case that is scheduled into released OR time is usually scheduled to be performed late in the day. This is because such a case is scheduled only a few days before the day of surgery, by which time the first case of the day starts have already been filled. When a case is scheduled into released OR time, if the surgeon and patient are flexible, then if possible arrange for the patient to be ready early in the day in the event that the case can and/or should be moved (11). The surgeon would be called as soon as an OR is finishing its scheduled cases, and the case moved into it. Moving cases on the day of surgery also has the benefit of reducing overutilized OR time (i.e., increasing OR efficiency) (12).

Some surgeons' offices may wait to schedule cases many days after knowing about them. For such organizations without enterprise-wide OR scheduling, a service may appear to have much allocated but unscheduled OR time, even though it does not. The work in this paper is based on the scheduler knowing how many hours of cases have been scheduled into allocated OR time, not how many have been entered into a computer. Before releasing allocated OR time, the scheduler should then first contact that service's office

to confirm the day's OR schedule and to give the office the opportunity to immediately post its scheduled cases.

Our results were sensitive to case duration and the number of ORs at the surgical suite. We showed that this was a direct consequence of the method used in this study to allocate OR time (Table 4). This is important, because it shows that the sensitivity is not a weakness in our findings. Specifically, our results are not limited to the surgical suite from whence the data came. Instead, our sensitivity analysis shows that it is the method of OR allocation on which our results depend.

We used a regularly scheduled workday of 8 hours. We used 8 hours to make interpretation of the results (Tables 1, 4) easier. The mathematics of OR allocation and case scheduling are identical when ORs have different durations, such as a mixture of 8-hour, 10-hour, and/or 13-hour ORs (1–4).

Our results apply to those surgical suites that allocate OR time and schedule cases to be as efficient as possible (1–3). Our results do not apply to facilities at which either (i) surgeons and patients are not able to choose the day of surgery, (ii) cases are turned away (e.g., if they would have to be scheduled into overutilized OR time), and/or (iii) OR allocations are not adjusted to maximize the efficiency of use of OR time. Different statistical methods are available for optimal OR allocation at such surgical suites, whether they care for all elective cases within a prespecified "reasonable" number of days and/or have a limited number of hours of OR time for elective cases. Our analysis does not apply to surgical suites that allocate fixed hours of OR time (i.e., "block" time), whether based on trying to increase OR utilization or hospital contribution margin.

In conclusion, at many surgical suites, surgeons and patients choose the day of surgery, cases are not turned away, and staffing is adjusted to maximize OR efficiency. Previously, we showed that if a service has filled its allocated OR time, OR efficiency is enhanced by scheduling, if possible, extra cases into the regularly scheduled OR time of a different service that has underutilized OR time (3). This is the OR management problem of "releasing" allocated OR time. In this study we showed that the service whose OR time is released can be the service with the largest difference between allocated and scheduled OR time at the moment when the new case is scheduled.

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