Use of Operating Room Information System Data to Predict the Impact of Reducing Turnover Times on Staffing Costs

Franklin Dexter, MD, PhD*, Amr E. Abouleish, MD, MBA†, Richard H. Epstein, MD‡, Charles W. Whitten, MD‖, and David A. Lubarsky, MD, MBA¶

*Division of Management Consulting, Department of Anesthesia, University of Iowa, Iowa City; †Department of Anesthesiology, University of Texas Medical Branch, Galveston; ‡Department of Anesthesiology, Jefferson Medical College, Philadelphia; §Medical Data Applications, Ltd., Jenkintown, Pennsylvania; ‖Department of Anesthesiology and Pain Medicine, University of Texas Southwestern Medical Center, Dallas; and ¶Department of Anesthesiology, Perioperative Medicine, and Pain Management and School of Business, University of Miami, Florida

Potential benefits to reducing turnover times are both quantitative (e.g., complete more cases and reduce staffing costs) and qualitative (e.g., improve professional satisfaction). Analyses have shown the quantitative arguments to be unsound except for reducing staffing costs. We describe a methodology by which each surgical suite can use its own numbers to calculate its individual potential reduction in staffing costs from reducing its turnover times. Calculations estimate optimal allocated operating room (OR) time (based on maximizing OR efficiency) before and after reducing the maximum and average turnover times. At four academic tertiary hospitals, reductions in average turnover times of 3 to 9 min would result in 0.8% to 1.8% reductions in staffing cost. Reductions in average turnover times of 10 to 19 min would result in 2.5% to 4.0% reductions in staffing costs. These reductions in staffing cost are achieved predominantly by reducing allocated OR time, not by reducing the hours that staff work late. Heads of anesthesiology groups often serve on OR committees that are fixated on turnover times. Rather than having to argue based on scientific studies, this methodology provides the ability to show the specific quantitative effects (small decreases in staffing costs and allocated OR time) of reducing turnover time using a surgical suite's own data.

(Anesth Analg 2003;97:1119–26)

When surgeons evaluated the performance of an academic anesthesiology department, they rated turnover times as the most important quality attribute with below average performance (1). Because neither revenue nor direct patient benefit is provided during clean up and set up times, reducing turnover times would seem to benefit both physicians and hospitals.

Analyses have studied the impact of reducing turnover times on increases in caseload (2,3) and on direct (4) and indirect (5,6) reductions in staffing costs. Achieved reductions from baseline average turnover times less than 40 min result in only small reductions in staffing costs, unless case durations are short (e.g., pediatric otolaryngology) (2–6).

At many surgical suites, there is a dichotomy between these scientific results (2–6) and the apparent importance attributed by surgeons (1) and other clinicians to turnover times. Many operating room (OR) committees are enamored of the topic. This dichotomy may be explained by the fact that clinicians are confronted with turnovers every workday but may not consider or understand concepts such as staffing costs and allocated OR time. Thus, to focus organizational attention toward quantitatively more important topics than turnover times, anesthesiologists and OR managers may need to evaluate the impact of changing each surgical suite's turnover time using its own data. One of the two goals of this paper is to describe how to calculate the staffing cost reduction achievable from reduction in turnover time by using OR information system data from a surgical suite.

Supported, in part, by the Foundation for Anesthesia Education and Research provided a Research Education Grant to (AEA).

Presented, in part, at the American Society of Anesthesiologists meeting in San Francisco, CA, October 2003.

Medical Data Applications (MDA), Ltd., developed and distributes CalculatOR™ software that performs the analysis described in this article.

Accepted for publication

Address correspondence and reprint requests to Franklin Dexter, Division of Management Consulting, Department of Anesthesia, University of Iowa, Iowa City, IA 52242. Address e-mail to Franklin-Dexter@UIowa.edu.

DOI: 10.1213/01.ANE.0000082520.68800.79

0003-2999/03

A second explanation for the dichotomy between scientific results and practice is that the scientific analysis of the direct effect of reducing turnover times on staffing costs considered small reductions in turnover time (4). This is appropriate for surgical suites with average turnover times of 40 min or less. Then, organizational efforts to reduce turnover times are often unsuccessful (1) or small. Average reductions of 7.1 min have been published but with the expense of changing from a standard OR to a minimally invasive one (7). A community hospital with an average turnover time of approximately 35 min achieved an average reduction of 8 to 10 min by using personal public recognition (a Tree of Excellence) and gift certificates to local restaurants and the hospital cafeteria donated by the surgeons and hospital (Personal communication with the Director of Perioperative Services, March 4, 2003).

In contrast, when average turnover times are longer than 40 min, larger reductions in turnover time have been described (e.g., 16-min average reduction from average of 57 min (8) and 13-min reduction from average of 65 min (9)). A second goal of this paper was to apply the turnover time analysis to four different tertiary hospitals with overall average turnover times ranging from 34 min to 66 min.

Methods

One year of data were collected from the OR information systems of four academic, tertiary hospitals. The data used for each case were the OR used, date and time that the patient entered his or her OR, date and time that the patient exited the OR, service performing the case, and whether the case was urgent. Holidays and weekends were excluded, because such days are known in advance to need less staffing than workdays.

We used the following definitions for the analysis:

Surgical service refers to a group of surgeons who share allocated OR time. In that we studied academic practices, most services were departments. However, one surgeon could represent a service. The services ranged from one to dozens of surgeons.

Regularly scheduled OR hours were the hours that individual OR team members plan on working (e.g., 7 AM to 5 PM). This excludes days when a team member is scheduled to work regular hours and to stay late if required "on call."

Allocated OR time is an interval of OR time with a specified start and end time on a specified day of the week that is assigned by the surgical suite to a service for scheduling its cases.

Case duration is defined as the time from when a patient enters an OR until he or she leaves the OR.

Turnover time is the time from when one patient exits an OR until the next patient on that day's OR schedule enters the same OR on the same day (10). If the first patient was cared for by a different service than the next patient, the turnover time was attributed to the first service when calculating OR workload (10).

Turnover times include clean up times and set up times, but not delays between contiguous cases in an OR. An example of a delay would be when the first patient of the day is found to have widespread metastases, resulting in cancellation of resection. The second case of the day in the OR will be performed by a different surgeon who will be unavailable for 3 h. To exclude delays, a maximum amount of time was ascribed to the turnover time (10). For example, suppose that the maximum turnover is 1.5 h. If the end and start of the two successive elective cases performed on the same day in the same OR were separated by 2 h, then a turnover time of 1.5 h was used. Previous studies used maximum turnovers of 1.0 h (5,10) or 1.25 h (6). We used an unusually long maximum turnover, since, as explained in the final paragraph of the Introduction, we intentionally studied some surgical suites with long average turnover times. When the methodology described in this paper is used at other surgical suites, a maximum turnover of 1.0 h would often be used.

Elective *OR workload* of a service is its total hours of elective cases including turnover times on that workday (11–13). Separate OR time was allocated on all days of the week for urgent cases.

Under-utilized OR time is the positive difference between allocated OR time and the OR workload (12,13). For example, if the service "Gynecology" was allocated an OR for 10 h from 7 AM to 5 PM but finished cases at 3 PM, the under-utilized OR time would be 2 h.

Over-utilized OR time is the positive difference between OR workload and allocated OR time. When allocated OR time and the regularly scheduled OR hours are the same (e.g., a service is allocated an OR for 10 h from 7 AM to 5 PM) and allocated OR time has not released, then over-utilized OR time is the hours that ORs run past the regularly scheduled OR hours (12,13). Also, then, hourly employees receive overtime when working during over-utilized hours.

Inefficiency of use of OR time equals the sum of two products: hours of under-utilized OR time multiplied by the cost per hour of under-utilized OR time and hours of over-utilized OR time multiplied by the cost per hour of over-utilized OR time (12,13). The cost per hour of over-utilized OR time is invariably more expensive than the cost per hour of under-utilized OR time.

OR efficiency is the value that is maximized when the inefficiency of use of OR time has been minimized (12,13).

For example, suppose that the hypothetical service "Dr. Smith" does 10 h of cases every Monday. A 0 h allocation would have a lower OR efficiency than an 8 h allocation because of 10 versus 2 over-utilized hours each Monday. An 8 h allocation would have a lower OR efficiency than a 10 h allocation because of 2 versus 0 over-utilized hours each Monday. Finally, a 13 h allocation would have a lower OR efficiency than a 10 h allocation because of 3 under-utilized hours each Monday. Thus, the service Dr. Smith would be allocated 10 h of OR time.

Staffing cost equals the allocated OR time for a service multiplied by its cost per hour plus the number of over-utilized hours multiplied by its cost per hour (4).

The cost of an over-utilized hour was considered to equal 1.75 times the cost of an under-utilized hour and of a regularly scheduled hour. This reflects both the direct costs of overtime or bonus pay at “time and a half” (1.50), plus an increment (0.25) for indirect costs of employee dissatisfaction and resignation, resulting in increased recruitment and retention costs.

For example, an anesthesiologist and a certified registered nurse anesthetist are scheduled to work 8 h from 7 AM to 3 PM (i.e., these are their regularly scheduled hours). The OR time is allocated for 8 h. However, since cases continue to 4 PM, they work until 4 PM. Then, the staffing cost was considered to equal the cost of 9.75 regularly scheduled hours, where 9.75 = (8 regularly scheduled OR hours) + 1.75 × (1 over-utilized hour).

The anesthesia cost of a regularly-scheduled hour was estimated at $119, based on the 2001 median annual United States (US) compensation for academic anesthesiologists of $198,413 (14) and for certified registered nurse anesthetists of $89,160 (14), 26% benefits, 2000 clinical hours per year, and staffing of 1 anesthesiologist to 2 nurse anesthetists (15). If both anesthesia and OR nursing costs were considered, the hourly cost would simply be increased appropriately.

We estimated how reducing turnover times would reduce staffing costs in three steps.

First, OR workload was calculated for each service on each day of the week using the previously described method (11–13) (CalculatOR™, Medical Data Applications, Ltd., Jenkintown, PA). All possible allocations of OR time were evaluated for the one that would have resulted in the maximal OR efficiency, options being 0 h, 8 h, 10 h, 13 h, 16 h, 18 h, and so forth. If providing 0 h to a service for a day of the week would have resulted in increased OR efficiency than providing 8 h, no OR was assigned to that service for that day of the week.

Although some services had an insufficient OR workload to be allocated OR time, OR time still required to be provided for them to schedule their cases. So that every surgeon has access to OR time on every workday (see first paragraph of Discussion), at least 8 h of OR time was allocated for the OTHER services on all workdays. This was also required because the methodology considered every case to be performed on the workday on which it was previously performed. For each day of the week, all services not allocated OR time were combined into an OTHER service. Some surgical suites refer to the OTHER service as “open OR time,” “unblocked OR time,” or “first-come first-served OR time.” The allocated OR time for the OTHER service was calculated as in the preceding paragraph.

Second, using the OR workload and the allocated OR time for each service from the first step, staffing costs were calculated by summing the staffing costs required among all services on all workdays of the studied year. All cases were considered to be scheduled on the same date that they were actually performed.

Third, the maximum turnover time was reduced for all cases from 90 min to 60, 50, 40, or 30 min. The first and second steps were repeated. The reduction in average turnover time and the difference in staffing costs between the 90-min maximum and the lower maximums were calculated.

Results

The 4 academic, tertiary hospitals had average turnover times of 34 to 66 min (Table 1). Reductions in average turnover times of 3 to 9 min would result in 0.8% to 1.8% reductions in staffing cost to complete the same cases by the same services on the same days of the week in each service’s allocated OR time. In units of 2001 US dollars, this is $52,000 to $151,000 annually of anesthesia staffing expenses at the 4 studied surgical suites. Reductions in average turnover time of 10 to 19 min would result in 2.5% to 4.0% reductions in staffing costs. This represents $151,000 to $243,000 annually at the 4 surgical suites.

These reductions in anesthesia staffing costs can be achieved provided OR allocations are reduced. Specifically, once turnover times are reduced, OR workload is less. Thus, while providing the surgeons with access to OR time on the workday they choose, the allocated OR time to maximize OR efficiency is less. Consequently, the reductions in staffing costs are achieved predominantly by reducing allocated OR time, not by reducing over-utilized OR time (Table 2).

For example, we consider the cystoscopy service on Mondays at Hospital D. At baseline, the allocation to maximize OR efficiency was 10 h for an average workload of 9 h (i.e., cases and turnover times lasted 9 h). There was considerable day-to-day variation in workload in that the allocation of 10 h provided average under-utilized OR time of 3 h and over-utilized OR time of 2 h. With a reduction in the maximum turnover time to 30 min, the average daily workload was

Table 1. Data for Weekday, Non holiday Cases at Each of the Four Academic, Tertiary Hospitals over 1 yr

Hospital	Number of ORs	Average turnover time (min) over the studied year	Number of turnovers per year	Average case duration (h) over the studied year	Number of cases over the studied year	Allocated OR time (h per workday)	Staffing cost (h per workday)[a]
A	28	34	10,444	2.8	17,507	250	278
B	18	38	5697	2.2	12,803	167	192
C	24	43	6603	2.6	12,769	183	208
D	33	66	7112	3.4	16,624	335	387

[a] Staffing cost in units of hours equals the allocated operating room (OR) time for a service plus the number of overutilized hours multiplied by the relative cost of a regularly scheduled to overutilized hour (see Methods for an example).

Table 2. Impact of Reducing Turnover Time on Staffing Costs at the Four Hospitals

Maximum turnover[a] time (min)	Hospital	Reduction in average turnover (min)	Anesthesia staffing cost reduction ($/yr)[b]	Staffing cost reduction (%)	Reduction in allocated OR time (hr/d)	OR workload reduction (h/d)	Overutilized OR time reduction (h/d)
60	A	3	$ 69,000	0.8	2.4	2.0	0.3
	B	4	$ 52,000	0.9	1.4	1.6	0.2
	C	4	$ 62,000	1.0	3.5	2.0	0.3
	D	13	$236,000	2.2	8.0	6.8	0.3
50	A	4	$102,000	1.2	2.9	3.1	0.6
	B	6	$ 74,000	1.3	1.7	2.4	0.4
	C	7	$110,000	1.8	5.8	3.1	−0.1
	D	20	$350,000	3.3	11.3	10.1	0.6
40	A	7	$151,000	1.8	4.1	4.5	0.8
	B	9	$102,000	1.6	2.2	3.4	0.7
	C	10	$152,000	2.5	6.2	4.6	0.5
	D	28	$464,000	4.4	14.2	14.1	1.5
30	A	10	$233,000	2.8	7.3	6.8	0.6
	B	13	$151,000	2.7	3.4	5.0	0.9
	C	16	$243,000	4.0	9.1	7.0	0.5
	D	37	$641,000	6.0	20.4	18.7	1.3

[b] Estimated using 2001 median U.S. annual compensation for anesthesia providers (see Methods), but with all other parameters from each hospital.
[a] Reducing maximum turnover time is an intervention described quantitatively using only one parameter—the maximum. This represents focusing efforts on causes of the longest of the turnovers at a surgical suite.

7 h. The OR allocation could be reduced to 8 h, without an increase in expected over-utilized OR time.

Discussion

Operational Decision-Making

Day-to-day operational decisions can be made based on four ordered priorities: (a) safety, (b) providing surgeons with access to OR time on the workday that they and their patients choose, (c) maximizing OR efficiency, and (d) reducing patient delays. These ordered priorities are sufficient to specify how OR time is allocated (11–13), cases are scheduled (16), OR time is released (17), elective and urgent cases are sequenced (18,19), cases are moved on the day of surgery (20), and staff are assigned on the day of surgery (21). In this paper, we showed that they are also sufficient to predict the effect of reductions in turnover times on staffing costs.

Applicability to Other Surgical Suites

The maximum potential reductions in staffing costs from reducing turnover times, while completing existing cases, were a few percent (Table 2). This is the same as that of other OR management interventions on the day of surgery (e.g., changing how add-on cases are scheduled (22)). However, such interventions do not cost anything, whereas efforts to reduce turnover times to an average less than approximately 30 minutes may require significant costs in and of themselves. Thus, we suspect that the principal benefit of our methodology to anesthesiologists will be to help them use their own data to show their OR committees why turnover time should not be their focus. Our experience is that the method may be most helpful when combined with benchmark data of turnover times.

We knew from previous simulation studies that the financial impact of achievable reductions in turnover time would be small (4). Our method, in fact, probably overestimates the reduction in staffing cost because it neglects any increase in cost that may be required to achieve the reduction in turnover times. The fact that the method generally overestimates the cost reduction can be put to advantage by heads of anesthesiology departments and OR managers using the methods.

When providing results to individuals focused on turnover times but not conversant in the science of OR management, it may be particularly useful to show that the financial benefit of reducing turnover times is achieved by reducing allocated OR time. An example is given in the last paragraph of the Results. The rationale is quite obvious in retrospect, and the implications for surgeons are clear.

The absolute reduction in staffing costs depends on the absolute reduction in the average turnover time. Ambulatory surgery centers will achieve smaller reductions in staffing costs than the hospitals in Table 2, because surgical suites starting with briefer turnover times can achieve smaller absolute reductions in average turnover time. Consequently, it is unlikely that our methodology can be of societal benefit unless it can be used to help focus organizational attention toward quantitatively more important topics than turnover times. Whether it can be is unknown, requiring future investigation.

Other Potential Benefits to Reducing Turnover Times

Advocates of reducing turnover time often state that doing so has additional benefits. Reducing turnover times could increase revenue by providing sufficient additional OR time to perform another elective case that would not otherwise have been economically sound to have been performed, prevent a case from being canceled out of concern that the case would finish after the end of regularly scheduled hours at a hospital aiming to reduce costs, permit a surgeon to perform another case in his or her OR that could not otherwise be completed, permit another add-on case to be performed that could not otherwise be completed within a fixed time period, reduce staffing costs, indirectly, by reducing the impact of erroneous turnover times on inaccurate allocations of OR time, and/or reduce case delays from scheduled start times. In the following paragraphs, we review why none of these arguments are true (2,3,5,6,23–25) (see Appendix). This is why our analysis focused on the direct effect of reducing turnover times on staffing costs.

Reducing turnover times could provide sufficient additional OR time to perform another elective case, thereby increasing revenue. The fallacy to this argument is that revenue enhancement is not an appropriate managerial goal. Rather, increasing contribution margin (revenue minus variable costs) is the relevant financial goal. Contribution margins per OR hour are consistently at least several hundred dollars and usually several thousand dollars (23,24). Consequently, if a case can be done safely, it would be irrational for a surgical suite concerned with contribution margin to perform a case if turnover times were reduced but not perform it if turnover times were not reduced. Even if OR teams were paid several hundred dollars per hour, it would make financial sense to perform the case, regardless of the turnover time, provided the case can be performed safely. For example, in the last paragraph of the Results, we describe how a reduction in turnover times for cystoscopy would result in a reduction in OR allocation. A false argument is that it would be better financially not to reduce staffing but instead to do more cases, because if increasing contribution margin was the goal, the additional cases would have been done even if turnover time had not been reduced.

Reducing turnover times could prevent a case from being canceled out of concern that the case would finish after the end of regularly scheduled hours and thus increase OR costs. The fallacy to this argument is that, then, presumably decision-making is being done to minimize costs. When OR time is allocated and cases are scheduled based on minimizing costs, then canceling a case to prevent small amounts of over-utilized OR time results in overall increased costs whether analyzed from a societal, hospital, physician, or patient perspective (25).

Reducing turnover times could permit a surgeon to perform another case in his or her OR that could not otherwise be completed within a fixed time period (not that there should be fixed time periods as explained in the preceding two paragraphs). The fallacy of this argument is that average turnover times are usually shorter than the mean absolute difference between scheduled and actual case durations (2). Thus, achievable turnover time reductions (4,7–9) would not permit another case to be scheduled and completed during the fixed time period, just performed on an add-on unscheduled basis (2). For example, suppose that Dr. Smith's total hip replacements have case durations of 3.7 hours ± 0.9 hours (mean ± SD); the statistical distribution is log normal (26); the cases are scheduled for 3.7 hours (27); the turnover times are 0.5 hours; and the fixed time period is 8 hours. Even if turnover times were zero, a new 0.5-hour case could not be completed within 8 hours on 44% of workdays (2,4). In fact, for 29% of days the new case would not even be started since its start time would be after the end of the 8-hour workday. Note that reducing turnover times is of value for surgeons with very short cases because there are many turnover times in one OR in a day, and short cases have small mean absolute differences between scheduled and actual durations (2).

Reducing turnover times could permit another add-on case to be performed that could not otherwise be completed within a fixed time period. The latter could be based on a safety criterion or on a fixed, externally specified budget. This argument is that although reducing turnover time may not be sufficient to do an extra scheduled case in one OR (2), if turnovers are reduced in many ORs, then an add-on case can be done in one of them. The fallacy to this argument is that it presupposes that the additional case could not be scheduled unless turnover time was reduced (3). When a short add-on case is submitted, usually there will be some OR into which the case can be scheduled at the end of the day even without a reduction in turnover time. Rather, it is only very long add-on cases that cannot otherwise be scheduled without a reduction in OR time. Yet, reducing turnover times do not add up to enough OR time in any one OR to permit scheduling of a very long case that could not otherwise have been scheduled (3). For example, at 4 PM of the day before surgery, there are 5 add-on cases. To maximize OR utilization (22), the OR manager considers the add-on cases in descending order of mean historical case duration: coronary artery bypass graft (4.5 hours), total hip replacement (3.7 hours), cholecystectomy (3 hours), orchiopexy (2.3 hours), carpal tunnel release (1 hours), and adenoidectomy (1 hour). One OR has 3.1 hours open, so the cholecystectomy is scheduled. Two other ORs have 1.6 hours and 1.1 hours open, so the carpal tunnel and adenoidectomy are scheduled. All other ORs have 0.7 hour or less of time remaining. Now the question applies whether reducing turnover times in one OR can achieve the additional 1.6 hours (2.3 hours–0.7 hours) required to schedule the orchiopexy.

Reducing turnover times could indirectly reduce staffing costs by reducing the impact of erroneous turnover times on producing poor allocations of OR time. Often surgical suites have limited or erroneous data concerning in which OR each case was performed. However, incorrect (5) or unknown (6) OR assignments cause increases in some measured turnover times and reductions in others. The net effect is too small to be financially important (5,6).

Reducing turnover times could reduce delays in cases starting after their scheduled start times. Reducing all turnover times could reduce delays, since the shorter the average turnover time, the less the chance that a delay would be substantial. However, we show in the Appendix that previously reported reductions in turnover times (7–9) would then only reduce average delays by 1–2 minutes. Reducing turnover times selectively for ORs with longer than average turnover times would be more fruitful, reducing average delays by 4–7 minutes. However, this is negligible compared with the reductions in time achievable by appropriately choosing when patients are ready for surgery based on quantitative analysis of OR information systems data (28). Unlike reducing turnover times, achieving the latter costs very little.

The principal benefit to a surgical suite in reducing turnover times is to reduce staffing costs. That is why, in this study, we described a methodology by which an anesthesiologist and/or OR manager can show stake holders at his or her surgical suite what would be the effect of reducing turnover time on staffing costs at their own surgical suite. The method will also show, for each potential reduction in average turnover time, by how much the surgeons' allocated OR time would be reduced.

Appendix

Impact of Reducing Turnover Times on Patient Delays

When analyzing the time to complete the preceding series of cases and turnover times in an OR, turnover times are, mathematically, short cases (27). Being right-skewed positive-valued distributions, we assume they follow log normal distributions (26). We include an overall mean μ of the natural logarithms of turnover times and a case effect c specifying variation of the natural logarithm of turnover times around that mean. We consider the turnover to be scheduled using the median of the durations of previous turnover times of the surgical suite, thereby being unaffected by the choice of the maximum turnover time. Then,

$$\text{Median turnover time} = \exp(\mu)$$

$$\text{Turnover time} = \exp(\mu + c)$$

$$\text{E(underestimate of turnover time)}$$

$$= \text{E}(\max(0, \exp(\mu + c) - \exp(\mu)))$$

We define:

$\Phi(z)$ Distribution function of a standard normal random variable z

f(c) Probability density function for normally distributed case (c) effect with 0 mean

The average underestimate of turnover time for a surgical suite equals

$$\text{E(underestimate of turnover time)}$$

$$= \text{E}(\max(0, \exp(\mu + c) - \exp(\mu)))$$

$$= \text{E}(\exp(\mu) \times \max(0, \exp(c) - 1))$$

$$= \text{E}(\exp(\mu)) \times \text{E}(\max(0, \exp(c) - 1)) \qquad (1)$$

$$= E(\exp(\mu)) \times \left(\int_{-\infty}^{\infty} \max(0, \exp(c) - 1) f(c)dc\right)$$

$$= \exp(\mu) \times \left(\left(\int_{0}^{\infty} \exp(c) f(c)dc\right) - \left(\int_{0}^{\infty} f(c)dc\right)\right) \quad (2)$$

$$= \exp(\mu)$$

$$\times \left(\int_{0}^{\infty} \exp(c)(\sigma_c\sqrt{2\pi})^{-1} \exp(-c^2/(2\sigma_c^2))dc - 1/2\right)$$

$$= \exp(\mu)$$

$$\times \left(\exp(\sigma_c^2/2)\int_{-\sigma_c}^{\infty} (2\pi)^{-1/2} \exp(-x^2/2)dx - 1/2\right)$$

$$= \exp(\mu) \times (\exp(\sigma_c^2/2)\Phi(\sigma_c) - 1/2). \quad (3)$$

In addition,

$$E(\text{turnover time}) = E(\exp(\mu + c))$$

$$= E(\exp(\mu)) \times E(\exp(c)) \quad (4)$$

$$= \exp(\mu) \times \exp(\sigma_c^2/2)$$

$$= \exp(\mu + \sigma_c^2/2) \quad (5)$$

We represent decreases in turnover times for a surgical suite by multiplying μ by a value g_s, $0 < g_s \leq 1$. From Equation (4), the ratio of the mean turnover time before and after intervention equals

$$R^s_{\text{turnover time}} = \frac{E(\exp(\mu)) \times E(\exp(c))}{E(\exp(g_s\mu)) \times E(\exp(c))} = \frac{E(\exp(\mu))}{E(\exp(g_s\mu))}$$

From Equation (1), the ratio of the mean underestimate of turnover time before and after intervention equals

$$R^s_{\text{under-estimate}} = \frac{E(\exp(\mu)) \times E(\max(0,\exp(c) - 1))}{E(\exp(g_s\mu)) \times E(\max(0,\exp(c) - 1))} = \frac{E(\exp(\mu))}{E(\exp(g_s\mu))} = R^s_{\text{turnover time}} \quad (6)$$

Thus, from Equation 1, the percentage decrease in the mean length of time that all turnovers finish after their scheduled times, before and after the intervention, equals the percentage change in the mean turnover time for all turnovers at the surgical suite before and after intervention. Results for Hospitals A–D, using previously reported reductions in turnover times (7–9), are given in column 3 of Table 3.

We represent decreases in turnover times selectively for cases that are running behind by transforming positive c to $g_c(c)$, $0 < g_c(c) \leq c$, while leaving unchanged turnovers with $c \leq 0$. From Equations (2), (3), (4), and (5), the ratio of the mean turnover times before and after intervention equals

$$R^c_{\text{turnover time}} = \frac{E(\exp(\mu)) \times E(\exp(c))}{E(\exp(\mu)) \times E(\exp(g_c(c)))}$$

$$= \frac{E(\exp(c))}{\int_{-\infty}^{\infty} \exp(g_c(c))f(c)dc} \quad (7)$$

$$= \frac{\exp(\sigma_c^2/2)}{\int_{-\infty}^{0} \exp(c)f(c)dc + \int_{0}^{\infty} \exp(g_c(c))f(c)dc}$$

$$= \frac{\exp(\sigma_c^2/2)}{\exp(\sigma_c^2/2)\Phi(-\sigma_c) + \int_{0}^{\infty} \exp(g_c(c))f(c)dc}$$

From Equations (2) and (3), the ratio of the mean under-estimates of turnover time before and after intervention equals

Table 3. Appendix - Impact of Reducing Turnover Times on Case Delays from Scheduled Start Times

		Reduction in average delay from case scheduled start time (min)[a]	
Hospital	Reduction in average turnover time (min)	Reducing all turnover times by equal proportion	Selectively reducing turnover times longer than average
A	10	2	7
B	10	2	6
C	15	2	7
D	20	1	4

[a] Using the notation in the Appendix, $R_{\text{turnover time}}{}^s$ was calculated using Column 2 and Column 3 of Table 1. From Equation (6), $R_{\text{underestimate}}{}^s$ was calculated from $R_{\text{turnover time}}{}^s$ and the baseline mean underestimate of turnover time for the hospital. Column 3 was calculated from $R_{\text{underestimate}}{}^s$, Column 4 of Table 1, and Column 6 of Table 1. Column 4 was calculated analogously.

$$R^{c}_{\text{under-estimate}} = \frac{E(\exp(\mu)) \times E(\max(0,\exp(c) - 1))}{E(\exp(\mu)) \times E(\max(0,\exp(g_c(c)) - 1))} = \frac{\exp(\sigma_c^2/2)\Phi(\sigma_c) - 1/2}{\int_0^\infty \exp(g_c(c))f(c)dc - 1/2} \quad (8)$$

Rearranging Equation (7) and substituting it into the denominator of Equation (8), the ratio of the mean under-estimates of turnover time before and after intervention equals

$$R^{c}_{\text{under-estimate}} = \frac{\exp(\sigma_c^2/2)\Phi(\sigma_c) - 1/2}{\left(\frac{\exp(\sigma_c^2/2)}{R^{c}_{\text{turnover time}}} - \exp(\sigma_c^2/2)\Phi(-\sigma_c)\right) - 1/2}$$

Values of σ_c were 0.621 for Hospital A, 0.594 for Hospital B, 0.572 for Hospital C, and 0.562 for Hospital D. Reductions inpatient delays are given in column 4 of Table 3.

References

1. Vitez TS, Macario A. Setting performance standards for an anesthesia department. J Clin Anesth 1998;10:166–75.
2. Dexter F, Coffin S, Tinker JH. Decreases in anesthesia-controlled time cannot permit one additional surgical operation to be scheduled during the workday. Anesth Analg 1995;81:1263–8.
3. Dexter F, Macario A. Decrease in case duration required to complete an additional case during regularly scheduled hours in an operating room suite: a computer simulation study. Anesth Analg 1999;88:72–6.
4. Dexter F, Macario A, Manberg PJ, et al. Computer simulation to determine how rapid anesthetic recovery protocols to decrease the time for emergence or increase the phase I post anesthesia care unit bypass rate affect staffing of an ambulatory surgery center. Anesth Analg 1999;88:1053–63.
5. Epstein RH, Dexter F. Uncertainty in knowing the operating rooms in which cases were performed has little effect on operating room allocations or efficiency. Anesth Analg 2002;95:1726–30.
6. Abouleish AE, Hensley SL, Zornow MH, et al. Inclusion of turnover time does not influence identification of surgical services that over- and underutilize allocated block time. Anesth Analg 2003;96:813–8.
7. Kenyon TA, Urbach DR, Speer JB, et al. Dedicated minimally invasive surgery suites increase operating room efficiency. Surg Endosc 2001;15:1140–3.
8. Overdyk FJ, Harvey SC, Fishman RL, et al. Successful strategies for improving operating room efficiency at academic institutions. Anesth Analg 1998;86:896–906.
9. Sokolovic E, Biro P, Wyss P, et al. Impact of the reduction of anaesthesia turnover time on operating room efficiency. Eur J Anaesthesiol 2002;19:560–3.
10. Dexter F, Macario A, Qian F, et al. Forecasting surgical groups' total hours of elective cases for allocation of block time: application of time series analysis to operating room management. Anesthesiology 1999;91:1501–8.
11. Dexter F, Epstein RH, Marsh HM. Statistical analysis of weekday operating room anesthesia group staffing at nine independently managed surgical suites. Anesth Analg 2001;92:1493–8.
12. Strum DP, Vargas LG, May JH, et al. Surgical suite utilization and capacity planning: a minimal cost analysis model. J Med Syst 1997;21:309–22.
13. Strum DP, Vargas LG, May JH. Surgical subspecialty block utilization and capacity planning: a minimal cost analysis model. Anesthesiology 1999;90:1176–85.
14. Medical Group Management Association. Academic practice compensation and production survey for faculty and management: 2002 report based on 2001 data. Englewood, CO: Medical Group Management Association, 2002.
15. Abouleish AE, Dexter F, Epstein RH, et al. Labor costs incurred by anesthesiology groups because of operating rooms not being allocated and cases not being scheduled to maximize operating room efficiency. Anesth Analg 2003;96:1109–13.
16. Dexter F, Traub RD. How to schedule elective surgical cases into specific operating rooms to maximize the efficiency of use of operating room time. Anesth Analg 2002;94:933–42.
17. Dexter F, Traub RD, Macario A. How to release allocated operating room time to increase efficiency: predicting which surgical service will have the most under-utilized operating room time. Anesth Analg 2003;96:507–12.
18. Dexter F, Macario A, Traub RD. Optimal sequencing of urgent surgical cases: scheduling cases using operating room information systems. J Clin Monit Comput 1999;15:153–62.
19. Dexter F, Traub RD. Sequencing cases in operating rooms: predicting whether one surgical case will last longer than another. Anesth Analg 2000;90:975–9.
20. Dexter F. A strategy to decide whether to move the last case of the day in an operating room to another empty operating room to decrease overtime labor costs. Anesth Analg 2000;91:925–8.
21. Dexter F, Macario A, O'Neill L. A strategy for deciding operating room assignments for second-shift anesthetists. Anesth Analg 1999;89:920–4.
22. Dexter F, Macario A, Traub RD. Which algorithm for scheduling add-on elective cases maximizes operating room utilization: use of bin packing algorithms and fuzzy constraints in operating room management. Anesthesiology 1999;91:1491–500.
23. Macario A, Dexter F, Traub RD. Hospital profitability per hour of operating room time can vary among surgeons. Anesth Analg 2001;93:669–75.
24. Dexter F, Blake JT, Penning DH, et al. Calculating a potential increase in hospital margin for elective surgery by changing operating room time allocations or increasing nursing staffing to permit completion of more cases: a case study. Anesth Analg 2002;94:138–42.
25. Tessler MJ, Kleiman SJ, Huberman MM. A "zero tolerance for overtime" increases surgical per case costs. Can J Anaesth 1997:44:1036–41.
26. Strum DP, May JH, Vargas LG. Modeling the uncertainty of surgical procedure times: comparison of the log-normal and normal models. Anesthesiology 2000;92:1160–7.
27. Dexter F, Traub RD, Qian F. Comparison of statistical methods to predict the time to complete a series of surgical cases. J Clin Monit Comput 1999;15:45–51.
28. Dexter F, Traub RD. Statistical method for predicting when patients should be ready on the day of surgery. Anesthesiology 2000;93:1107–14.