Lack of Sensitivity of Staffing for 8-Hour Sessions to Standard Deviation in Daily Actual Hours of Operating Room Time Used for Surgeons with Long Queues

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BACKGROUND: At multiple facilities including some in the United Kingdom's National Health Service, the following are features of many surgical-anesthetic teams: i) there is sufficient workload for each operating room (OR) list to almost always be fully scheduled; ii) the workdays are organized such that a single surgeon is assigned to each block of time (usually 8 h); iii) one team is assigned per block; and iv) hardly ever would a team "split" to do cases in more than one OR simultaneously.

METHODS: We used Monte-Carlo simulation using normal and Weibull distributions to estimate the times to complete lists of cases scheduled into such 8 h sessions. For each combination of mean and standard deviation, inefficiencies of use of OR time were determined for 10 h versus 8 h of staffing.

RESULTS: When the mean actual hours of OR time used averages ≤8 h 25 min, 8 h of staffing has higher OR efficiency than 10 h for all combinations of standard deviation and relative cost of over-run to under-run. When mean ≥8 h 50 min, 10 h staffing has higher OR efficiency. For 8 h 25 min < mean <8 h 50 min, the economic break-even point depends on conditions. For example, break-even is: (a) 8 h 27 min for Weibull, standard deviation of 60 min and relative cost of over-run to under-run of 2.0 versus (b) 8 h 48 min for normal, standard deviation of 0 min and relative cost ratio of 1.50. Although the simplest decision rule would be to staff for 8 h if the mean workload is ≤8 h 40 min and to staff for 10 h otherwise, performance was poor. For example, for the Weibull distribution with mean 8 h 40 min, standard deviation 60 min, and relative cost ratio of 2.00, the inefficiency of use of OR time would be 34% larger if staffing were planned for 8 h instead of 10 h.

CONCLUSIONS: For surgical teams with 8 h sessions, use the following decision rule for anesthesiology and OR nurse staffing. If actual hours of OR time used averages ≤8 h 25 min, plan 8 h staffing. If average ≥8 h 50 min, plan 10 h staffing. For averages in between, perform the full analysis of McIntosh et al. (Anesth Analg 2006;103:1499–516).

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Progress has been made in the science of operating room (OR) management for planning anesthesiologist staffing (i.e., numbers each workday for each specialty and the appropriate hours to be scheduled). Much of that work has been designed for hospitals with substantial variability in workload day to day[1] and among ORs.[2,3] Some surgeons' workloads are quite variable, because daily caseload depends on recent success in attracting patients.[4,5] However, some surgeons have queues persistently longer than 4 wk (e.g., in the United Kingdom's National Health Service [NHS]). Suppose that 1) sufficient workload exists such that each surgical-anesthetic team's OR list can almost always be fully scheduled; 2) the workday is organized such that a single surgeon (i.e., "*surgical team*") is assigned a fixed block of time (usually 4 or 8 h); 3) there is one team per block; and 4) hardly ever would (or can) a team "split" to do cases in more than one OR simultaneously or use part (e.g., 2 h) of another team's block time, even if available. This article tests the hypothesis that, under these circumstances, a simplified statistical analysis may be practical when one anesthesiologist is assigned to each 8 h session or pairs of 4 h sessions.

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Background: Matching Staff Scheduling to the Actual OR Workload

For simplicity of review,[2] consider a hypothetical team with an 8 h session for its lists of cases each Monday from 9:00 AM to 5:00 PM. However, let us also assume for discussion that the time of the last patient's exit from the OR is always 6:15 PM. The mean ± SD of the actual hours of OR time used by the team on Mondays is 9 h 15 min ± 0 min. Although the "±0 min" is irrelevant now, we use the format consistently throughout the article for realistic standard deviations.

We do not ask: "What is the length of the session presently budgeted for case scheduling?" The answer to that question is 8 h. Also, we do not ask: "How many hours do the anesthesiologist and OR nurses currently work on Mondays?" The answer to that question is 9 h 15 min. Our question is: "How many hours *should* the anesthesiologists be scheduled to work on Mondays?" The answer is 9 h 15 min, because those are the hours that they work, whether they want to or not.[6]

Equations, that answer this question systematically for when the standard deviation is not an unrealistic 0 h, rely on the terms "*under-run*," "*over-run*," and the "*efficiency of use of OR time*." Although the first two terms are identical to under-utilized and over-utilized OR time, respectively,[2,7] we use "under-run" and "over-run" since they are common vernacular phrases in hospitals with surgical teams allocated 8 h sessions. An under-run occurs when the time allocated to a team exceeds the actual hours of work (and the over-run equals zero).[7] Conversely, an over-run occurs when the time allocated to the team is less than or the same as the actual hours of work (and the under-run equals zero). In our above example, we assumed that the time allocated to the team was 8 h, but found that the actual hours of work were 9 h 15 min. There was an over-run of 1 h 15 min and no under-run. Had the time allocated to the team in the OR been the alternative option of 10 h, then for the same actual hours of work, the OR would have had an under-run of 45 min and no over-run.

Central to the analysis is that a 1 h over-run costs more than a 1 h under-run.[2,7–9] Otherwise, the mathematics would consider staff to be equally pleased and compensated for performing elective cases at 1:00 PM or 10:00 PM. Apparently they are not, since over-runs are the most common cause of disagreements among staff in the type of hospitals under consideration.[10] The relative cost ratio includes the intangible cost of that conflict, which reflects the personal cost of after-hours work.

In equation form, the cost of the daily *inefficiency of use of OR time* can be proportional to the sum[2,7]:

$$\text{(the hours under-run)} + \kappa \text{ (the hours over-run)}, \qquad (1)$$

where the relative cost ratio κ is greater than 1. In our analysis, we consider $\kappa = 1.50$ and $\kappa = 2.00$. When a staff member works late and submits an overtime claim, the cost can exceed their base pay by an equal amount (i.e., $\kappa = 2.00$). Equation 1 considers only the scheduling of OR staff, because the expenses for consumables are generally proportional to the actual hours worked, not the hours scheduled.

None of the material so far differs from that of our 2006 review of optimal staffing of OR time to minimize the mean (expected value) of Eq. 1 over many days.[2,7] If allocated staffing for 8 h, then our Monday team, above, would always over-run by 1 h 15 min. From Eq. 1 and with $\kappa = 2.00$, the cost of the daily inefficiency of use of OR time would be a fiscal value (in local currency) proportional to 2 h 30 min, where 2 h 30 min = 0 h under-run + 2.00 × 1 h 15 min over-run. If the allocated staffing was for 10 h, then the team would consistently under-run by 45 min. The cost of the daily inefficiency of use of OR time would be proportional to 45 min. Since the costs are proportional to the times, the inefficiency of use of the OR staff would be lower by allocating 10 h of time than 8 h of time. Months ahead, the anesthesiologists and OR nurses should be scheduled to work 10 h.

Despite this action, the numbers of cases scheduled and actual hours staff work are identical to the situation that existed before any rescheduling occurred. From the perspective of the surgical team and the patients, the OR capacity is identical. The change is simply to *plan* ahead for the extended workday instead of suffering every Monday from the *unplanned but inevitable* over-run. The consequence of this rescheduling of work hours is an increase in the efficiency of use of OR time and reduction in labor costs.[2] Epidemiologically, pooling published case series, 11 of 13 facilities found the calculated reduction in labor costs to exceed 10%.[2]

Now consider a different scenario, but still with a zero standard deviation.[11] Suppose that every Monday every OR is filled for 8 h 40 min, from 9:00 AM to 5:40 PM. If each team were allocated 8 h of staffing, the daily over-runs would be 40 min ± 0 min. If the relative cost of over-utilized to under-utilized OR time equals 2.0, then the cost of the inefficiency of use of OR time on Mondays would be proportional to 1 h 20 min, where 1 h 20 min = 0.0 h under-run + 2.0 × 0 h 40 min over-run. With 10 h of staffing, the inefficiency of use of OR time on Mondays would also be proportional to 1 h 20 min, where 1 h 20 min = 1 h 20 min under-run + 2.0 × 0.0 h over-run (Fig. 1). Since the two are the same, 5:40 PM is the economic "break even" point for a change from 8 h of allocated staffing to 10 h of staffing on Mondays.[2,7,11] If a surgical-anesthetic team always over-runs by 40 min, then it is economically beneficial to staff for 10 h instead of 8 h. Again, the 8 h and 10 h refer only to the hours for the anesthesiologists' and OR nurses' staff scheduling.[2]

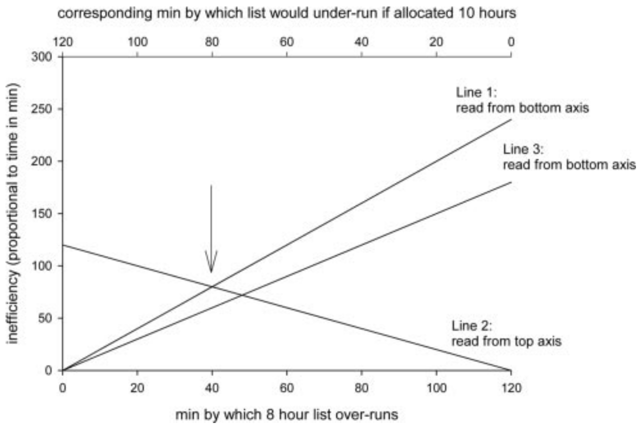

Figure 1. Estimating the time point at which an 8 h list justifies a 10 h list allocation. The bottom x axis refers to the time in minutes that an 8 h list might regularly over-run, and corresponds to the inefficiency of use of theater time on the y axis for the marked relationship, Line 1. The top x axis refers to the corresponding time in minutes if this same list were instead allocated 10 h. This corresponds to the inefficiency on the y axis for the marked relationship, Line 2. Note that the slope of Line 1 is twice as great as that for Line 2, since the plot assumes that the ratio of cost of an over-run to cost of an under-run is 2. If this ratio were smaller, then the slope of Line 1 would be correspondingly smaller. The time point at which the two inefficiencies are equal is 40 min over-run (marked by vertical arrow). Line 3 is a hypothetical line that assumes the ratio of cost of an over-run to cost of an under-run is just 1.5. Note that the intersection of Line 3 and Line 2 is little different from 40 min, as explained in the text. The graph may be read the other way also: if a 10 h list were consistently under-used, 80 min under-run would be the time which justifies its reallocation to 8 h instead of 10 h.

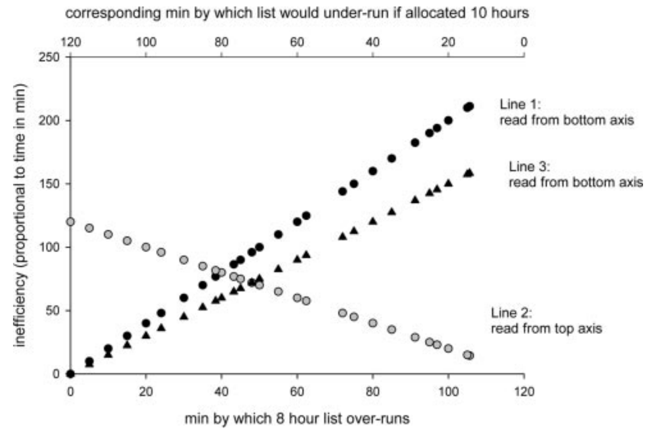

Figure 2. Application of the principles of Figure 1 to data from a gynecology team at a United Kingdom National Health Service hospital. The 54 consecutive lists have mean ± SE of over-run beyond 8 h session of 64 min ± 8 min. Lines 1 to 3 are as defined in the caption for Figure 1. There are many fewer than 54 data points plotted because of overlap.

If the standard deviation of the actual hours of work equals 0.0 h, as in the preceding simplistic examples, then it is trivial to calculate that 10 h of staffing has a higher OR efficiency than does 8 h of staffing when the over-run is greater than 40 min and the relative cost of 1.0 h of over-run to 1.0 h of under-run equals 2.0. More generally, Eq. 1 can be rearranged to show that 8 h + 2 h/(κ + 1) equals the break-even number of hours between staffing best allocated for 8 h or 10 h. For example, when $\kappa = 2.00$ as above, this works out to 8 h 40 min, as shown in the preceding paragraph.

Of course, teams' lists do not have standard deviations of actual hours of cases of 0 min. For example, Figure 2 shows data for a surgical team that consistently over-runs its 8 h sessions. It is not trivial to calculate the economically preferred mean actual hours of cases and turnovers when the standard deviation of actual hours worked is not 0.0 h. Prior studies used actual daily workloads over months so that staffing decisions could incorporate the variability among weeks in the actual hours of cases.[2,12] In the current article, we examine the conditions under which the mean alone is sufficient to decide between allocating 8 h or 10 h, by exploring the influence of different statistical models, standard deviations, and relative cost ratios on results.

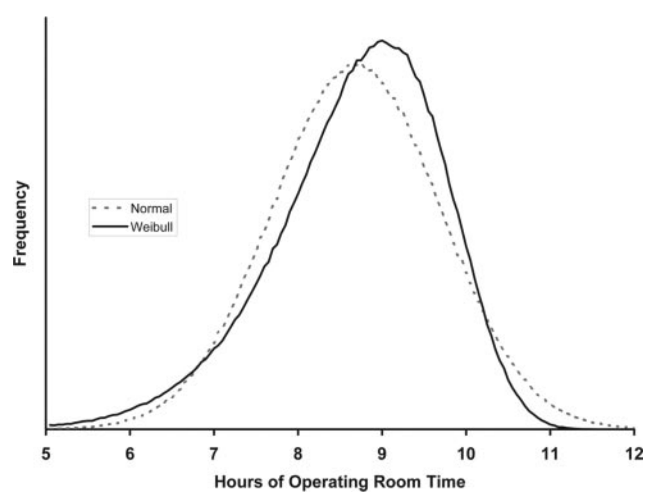

Figure 3. Comparison of normal and Weibull probability densities. The statistical distributions of the times to complete lists of cases generally follow either normal or Weibull probability distributions.[7] Using Systat 12, we simulated 150,000 random numbers each for normal and Weibull distributions with mean ± SD = 8 h 40 min ± 1 h 0 min. The bins in increments of 0.1 h were then connected. The figure shows that the Weibull distribution has larger kurtosis and negative kurtosis relative to the normal distribution.[33]

METHODS

Strum et al.[7] showed that the statistical distributions of the times to complete lists of cases usually follow either normal or Weibull probability distributions (Fig. 3). Since both normal and Weibull distributions have two parameters, specification of the mean and standard deviation of the actual hours of OR time is sufficient to uniquely define each statistical distribution.

As explained above, 8 h 40 min is the economic break-even point for 10 h of staffing to be planned for an 8 h session, with a 0 min standard deviation. Figure 3 shows the normal and Weibull distributions for the actual hours of OR time, assuming a mean time of 8 h

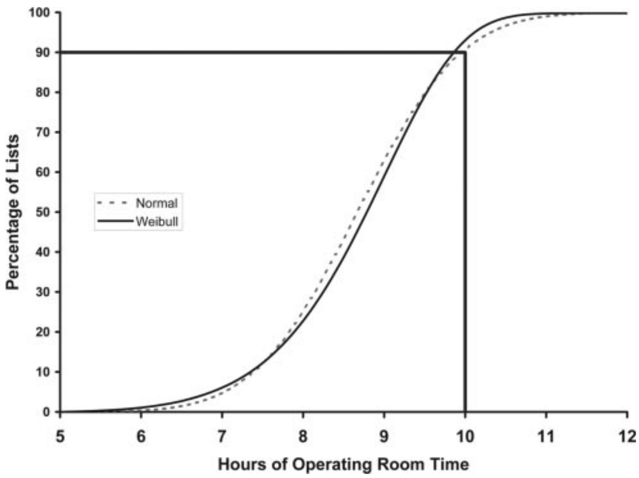

Figure 4. Comparison of Normal and Weibull cumulative distributions. Generation from mean ± SD = 8 h 40 min ± 1 h 0 min is as described in Figure 3. For the normal distribution, 9 h 57 min is the 90th percentile. For the Weibull distribution, 9 h 51 min is the 90th percentile. The limit lines are drawn at 10 h 0 min and 90%.

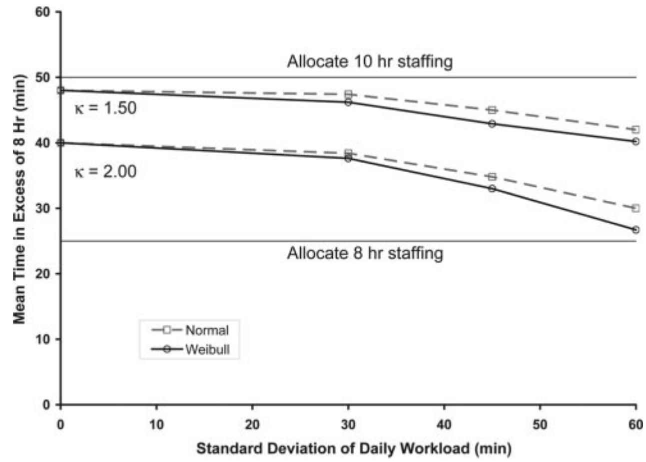

Figure 5. Dependence of the economic break-even point for the mean daily actual hours of operating room time used on the standard deviation of the daily actual hours and on the relative cost of 1 h of over-run to under-run. The horizontal lines are our recommended decision rule as described in the Results.

40 min and a standard distribution of 1 h 0 min. Figure 4 shows the cumulative probability distribution for the actual hours. Approximately 1 list out of 10 exceeds 10 h 0 min.

We used Monte-Carlo simulation to investigate the extent to which variability in actual hours of used OR time affected our trivial calculation that, for $\kappa = 2.00$, 8 h 40 min was the economic break-even point between allocating 8 h and 10 h of staffing. We used Monte-Carlo simulation to generate actual hours of lists with means of 8 h 40 min, two probability distributions (normal and Weibull), and two standard deviations (0 min and 1 h 0 min). These simulated data were used with Eq. 1 to calculate the percentage incremental cost of the inefficiency of use of OR time of treating 8 h 40 min as the break-even point. Simulation using Systat 12 was continued until the absolute error of the percentage increment was <0.2% (SYSTAT Software, San Jose, CA). We considered an increase in the inefficiency of use of OR time of <5% to be negligibly small (see our review Ref. 2). We used $\kappa = 2.00$ as our baseline value in Eq. 1.

Next, for each combination of parameters, we found the time between 8 h 0 min and 10 h 0 min that is the economic break-even point, by using the following steps:

1. Started with an initial guess for the break-even point of mean equal to 8 h 40 min.
2. Iteratively calculated the two parameters of the Weibull distribution, to within 10^{-6}, that correspond to the specified mean and a standard deviation of 60 min (Premium Solver Platform 7.0 for Excel, Frontline Systems, Incline Village, NV).
3. Generated 25,000 random numbers from the probability distribution of step 2.
4. For each of the randomly drawn total actual hours of cases and turnovers from step 3, calculated the inefficiency of use of OR time using Eq. 1.
5. If the mean inefficiency of use of OR time was greater with 8 h staffing versus 10 h staffing, increased the mean break-even point and repeated step 2. If the opposite, reduced the mean break-even point and repeated step 2. Stopped when the inefficiency of use of OR time was the same within 0.1 min.
6. Repeated steps 1 through 5 using normal probability distribution.

Finally, we repeated all of the above using a relative cost of an over-run to under-run of 1.50.

RESULTS

Figure 5 shows the dependence of the economic break-even point for the mean daily actual hours of OR time used on the standard deviation and on the relative cost of 1 h of over-run to under-run. The normal and Weibull distributions generated similar results. For $\kappa = 1.50$, the break-even point is 8 h 48 min when the standard deviation is 0. The break-even points are 8 h 42 min for normal distribution and 8 h 39 min for Weibull distribution. For $\kappa = 2.00$, the break-even point is at 8 h 40 min when the standard deviation is 0. The break-even points are 8 h 30 min for normal distribution and 8 h 27 min for Weibull distribution.

The consistency of the results suggests the following rational decision rule. If actual hours of OR time used average ≤8 h 25 min, then plan 8 h staffing. If the actual hours average ≥8 h 50 min, then plan 10 h staffing. If actual list duration averages in between 8 h 25 min and 8 h 50 min, perform a full analysis using historical data, as reviewed in Ref. 2.

An alternative decision rule would be to staff for 8 h if the mean workload is ≤8 h 40 min and to staff for 10 h otherwise. This rule performs poorly. For example, for a Weibull distribution with mean 8 h 40 min, standard deviation 60 min, and relative cost ratio of 2.00, the inefficiency of use of OR time is 34% larger if staffing is planned for 8 h instead of 10 h.

DISCUSSION

A common OR management structure in some public hospitals including NHS is to have one surgical team per 8 h session, most sessions full with several month queues, and cases hardly ever moved from one anesthesia team (OR) to another. For hospitals for which this is a typical model (e.g., Fig. 2), we have shown that large simplification can be made to an extensive prior literature in OR management.[2,8,7,11–13] The mean time of the end of the session may be sufficient to decide whether to plan 8 h or 10 h of staffing. The results are practical in that a NHS hospital recently reported that their median over-runs were 50 min.[14] This hospital's efficiency of use of theater time would be greater if many ORs were scheduled for 10 h (e.g., two-and-a-half 4 h sessions) instead of 8 h (e.g., two 4 h sessions).

Prior studies in the operations research literature have also found insensitivity of results to the ratio of the cost of 1 h of over-runs to 1 h of under-runs and to the probability distribution, for a specified mean and standard deviation.[15,16] However, these studies could not be applied directly to OR staffing, since they made assumptions appropriate for management of numbers of physical items (e.g., vials of propofol) rather than assets such as OR staffing that cannot be stored from one day to the next.[15,16]

It has been shown that the studied decisions are insensitive to accuracy of estimation of case durations.[1,2,6,8,11,13] When estimation is poor, more ORs over- (or under-) run and staffing is rescheduled as above to match the reality of the work hours that result from this over- (or under-) running. The effects of bias and imprecision of case duration predictions are essentially built into the mean and standard deviation of the actual hours of OR time used, respectively.[1,2,8]

At those facilities to which our article applies, tactical and strategic decisions are generally made by strategic health authorities, Departments of Health, etc. Even if local hospitals have some responsibility for decisions, their decision choices are constrained by rules and limits set by these authorities.[17] Thus, we confined our analysis to interventions that hospitals themselves generally can make: staff scheduling,[2] case scheduling,[8,9] and day-to-day running of an OR control desk.[9,13] Readers interested in the longer-term tactical decisions for capacity expansion can refer to a recent review of the topic.[18]

Application to "Gaps" Between Cases

Our findings can be used to simplify determination for when there is or is not large potential benefit of reducing turnover times. Concepts will be the same whether *turnover time* refers to "wheels out" to "wheels in" or to the time from when the anesthesiologist assigned to a list finishes caring for one patient and starts to care for the next patient.[19,20] Reductions in turnover times can mitigate the adverse impact of over-runs and/or reduce the frequency of use of 10 h staffing needed for 8 h sessions that are consistently over-running.[2,21]

Before the new findings of our article, the only simple result was to say that turnover time reductions should be targeted toward teams averaging more than 8 h of actual OR use per workday.[2] For example, consider a team whose workload on Tuesdays is 6 h 40 min ± 55 min. Then, the team's allocation should be 8 h, as summarized above. There are so few minutes of over-runs (1 min ± 8 min, based on a normal distribution) that the effect of turnover time reduction would be just further increases in under-runs. In contrast, another team's actual hours of OR time is 8 h 25 min ± 35 min. Then, an 8 h allocation results in 30 min ± 28 min of over-runs, using the normal distribution. If each minute over-run costs twice as much as each minute of scheduled time on a long-term basis, then each 1 min reduction in turnover time results in a mean of 1 min 31 s cost savings. There are many such examples in our prior review article.[2]

Our Results permit greater sophistication to the analysis. Suppose that a team's mean actual hours of OR time ranges from 8 h to 8 h 25 min. Then, each minute reduction in turnover time represents a reduction in over-runs, and the team should be targeted. In contrast, for a team for which the mean actual hours of OR time used minus the mean daily potential reduction in total turnover time would exceed 8 h 50 min but be <10 h, likely the staff scheduling will remain 10 h regardless of turnover time reduction. In between the narrow range of 8 h 25 min to 8 h 50 min, the full analysis in Ref. 2 remains necessary.

Staff Scheduling and Case Cancellation

The concepts underlying the statistical methods are important when planning OR nurse and anesthesiologist staff schedules.[11,22–24] Suppose that a surgical team, regularly performing many short cases, has actual hours of OR use of 8 h 0 min ± 40 min and based on the above methods, the decision is made to plan 8 h of staffing from 9:00 AM to 5:00 PM. Staff scheduling must then be planned, in advance, such that if the last case in a list is reasonably scheduled for 30 min duration and would start at 5:00 PM, the case would not be cancelled. Since the standard deviation of actual OR hours is 40 min, sometimes such late work will happen. The over-runs are considered to cost more than work within regular hours, because the nurses and anesthesiologists are working late (ratios >2.0 may be appropriate to include the indirect/intangible costs if cancellation were to occur).[25,26] How many OR nurses and anesthesiologists to be scheduled in advance to work late if needed can be calculated based on minimizing expected labor costs.[11,22–24]

Statistical Details

Although we have shown that implementation of the methods is as simple as calculating the mean, other details can be important. Decisions between allocating 8 h or 10 h are typically the same whether the data used in their calculations are the times of the start/end of anesthesia, of the entrance/exit from ORs, or start/end of monitoring vital signs in ORs.[24,27–29] Decisions are generally insensitive to common errors in the data, such as the specific OR in which a patient has surgery.[30,31] Nine months of data is a suitable period for analysis.[12] Seasonal variation generally has minimal or no influence on decisions.[32]

One limitation of our article is that it is predicated on there being long patient queues for surgery (e.g., average waits exceeding 4 wk).[4,5] If queues are short, the time series of a team's lists of under-runs and over-runs are statistically correlated, resulting in inaccurate estimation of the true mean from the sample mean.[4,5] When waiting times are briefer, allocations are best planned by specialty and incorporate the movement of cases between ORs on the day of surgery.[2,4,5,8]

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