Determining staffing requirements for a second shift of anesthetists by graphical analysis of data from operating room information systems

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Some operating room (OR) managers face the dilemma whereby all cases in a surgical suite are not completed during a regularly scheduled (eg, 8-hour) day. If the anesthesia group at the surgical suite plans for its employed anesthetists to work a fixed number of hours each day, then more than 1 shift of anesthetists may be needed to care for the patients in the ORs. We developed a graphical statistical method that anesthetists and anesthesiologists can use to determine how many anesthesia providers are required on the second shift to minimize labor costs. The method uses data from surgical services information systems or hospital information systems to compensate for seasonality or seasonal variation in the number of ORs running at different times of the day. We also consider application of our method to scheduling surgical nurses with multiple overlapping shifts throughout the day.

Key words: Health economics, operating room information systems, operating room management, staff scheduling.

Introduction

Some surgical suites face the dilemma whereby all cases are not completed during a regularly scheduled (eg, 8-hour) day. If a group of anesthetists or a hospital plans for its employed anesthetists to work a fixed number of hours each day (eg, 8 hours), then more than 1 shift of anesthetists may need to be scheduled to care for the patients in the operating rooms (ORs). The number of anesthetists scheduled to work during a first shift characteristically equals at least the number of staffed operating rooms in a surgical suite. In contrast, the number of anesthetists scheduled to work during a second shift may, intentionally or unintentionally, be smaller than the number scheduled to work during the first shift. On some days, anesthetists from the first shift must remain until cases in their ORs finish. If an anesthesia group were to staff the second shift, intentionally or unintentionally, with a sufficient number of anesthetists to relieve all of the anesthetists working the first shift, then for at least part of the second shift, some anesthetists may not be doing cases.

The goal of this article is to describe a graphical statistical method that we developed to assist an anesthesia group to decide how many anesthetists the group should assign to work during a second shift to minimize labor costs. A graphical approach does not allow us to achieve a statistical proof for the numbers of anesthetists required. However, the use of a graphical method provides us with a very good estimate using data typically available from an OR information system.

The focus of this article is on the anesthetist *staffing* decision. Using terminology from the management sciences literature, the staffing decision refers to the determination of the number of anesthetists to be employed on a permanent basis. Characteristically, this decision is made every 6 to 12 months, but it can be made more frequently. In contrast, the *scheduling* decision is an intermediate-range problem to determine the days and shifts when each anesthetist is to report to work.[1,2] In other words, if an anesthesia group employs 3 anesthetists, the staffing decision may indicate that 2 anesthetists work during the first shift and 1 anesthetist works the second shift. The scheduling decision would specify which of the 3 anesthetists will work the second shift during the next scheduling period. The scheduling decision begins with an agreed-on level of patient care for each shift during the scheduling period. Thus, the minimum number of anesthetists to be assigned daily to each shift is assumed to be known from the staffing decision before the scheduling decision commences.[1] The focus of this article is the staffing decision, not the scheduling decision.

Methods

The problem of determining anesthetist staffing to minimize costs requires specifying mathematically relevant characteristics of anesthetists' work.

1. Anesthetist labor costs are minimized by scheduling each patient's day of surgery in a manner to minimize day-to-day variation in the surgical suite's workload[3] and then assigning cases to ORs in a manner to try to achieve the same number of hours of elective cases in each OR of the surgical suite.[4] However, because of variation in workload for urgent cases, lack of control over OR scheduling, or both, some anesthesia groups face day-to-day variation in the workload of their second shift of anesthetists. Part-time anesthetists who are not scheduled to be "on call" generally are not available to be called into work with a few hours' notice. The implication is that costs associated with having too few or too many anesthetists on a second shift generally cannot be eliminated.

2. Anesthetists who are employed by an anesthesia group are paid on a salaried or an hourly basis, as defined by the Fair Labor Standards Act; characteristically they are salaried. Payment on a *salaried* basis is defined as a set salary paid regardless of the number of hours worked each week. Payment of an *hourly wage* requires an overtime wage of 1.5 times the *regular rate* for work beyond 40 hours a week averaged over a prespecified number of weeks. We refer to the cost when an anesthetist works **o**vertime or later than the shift to equal C_o times the cost of working during a regularly scheduled shift. The relative valuation of overtime to regular time can be based solely on wage. Then, for salaried anesthetists $C_o = 1.0$, and for hourly anesthetists $C_o = 1.5$. On the other hand, if an anesthesia group pays anesthetists on a salaried or hourly basis, and yet because of a large number of hours worked each day the anesthetists continue to leave the anesthesia group, then $C_o > 1.0$ or $C_o > 1.5$, respectively.

3. Anesthetists typically are scheduled in increments of 4 weeks (ie, 4, 8, or 12 weeks). In addition, as mentioned in characteristic #2, the Fair Labor Standards Act specifies that anesthetists who are paid an hourly wage receive overtime for work beyond 40 hours a week averaged over the payment period, which at many hospitals is 4 weeks. The implication of this is that our graphical analysis can consider 4-week periods. Historical data for numbers of ORs running during the second shift to be used to make staffing decisions are obtained for consecutive 4-week periods from the oldest period with data ($i = 1$) to the most recent period with data ($i = N_p$).

4. The number of anesthetists required for a second shift may vary seasonally or progressively over time from $i = 1$ to N_p. Therefore, the number of periods with data (N_p) should contain as many years of reliable data as available from the surgical suite's information system. For example, evaluation of seasonality or variation among seasons of the year generally requires at least 3 years of data or 39 four-week periods. If during the period of data collection there was a change in the policy for how cases are scheduled in the surgical suite, the duration of the regularly scheduled OR day, or the number of ORs, data from preceding dates may not be helpful for choosing appropriate numbers of anesthetists for future staffing.

5. The number of work days with data from the i^{th} 4-week period (N_{di}) varies among 4-week periods because of holidays. The consecutive work **d**ays within the i^{th} period are numbered sequentially from the oldest work day within the period ($j = 1$) to the most recent date $j = (N_{di})$. Generally, N_{di} equals 19 or 20 work days.

6. The number of anesthetists working a first shift characteristically is fixed by the number of anesthetizing locations. There are 2 implications of this characteristic for the staffing problem. First, only the number of anesthetists to be scheduled for the second shift is an unknown value (ie, determining how many anesthetists to work the first shift is generally straightforward). Second, there is no opportunity cost or economic sacrifice (above that of the wages) sustained in scheduling more anesthetists than needed to care for all of the patients during the second shift. A surgical suite generally does not have empty ORs during the first shift because an anesthetist was scheduled to work the second shift.

7. There is a requirement for continuous presence, meaning that once a case starts, it is not preempted or stopped at the end of an anesthetist's shift. An anesthetist cannot stop working and come back to a patient after a break or on the next work day. This requirement can be understood by comparing the activities, for example, with those of an accountant. We consider the second shift to **s**tart at the h_s hour (eg, 3 PM). The **f**inal hour of the second shift starts at the h_f hour (eg, h_f = 10 PM providing for the second shift to end at 11 PM). We let n_{ijk} refer to the number of ORs needed to be staffed starting at each hour k = h_s, …, h_f during the jth work day of the ith period. We use the symbol "s" to refer to the number of anesthetists working a second shift. Then, on the jth work day of the ith period, the cost of anesthetists assigned to work the first shift who must continue to work after the start of the second shift equals the (equivalent hourly salary) ×

$$\sum_{k=h_s}^{h_f} C_o \max\left(0, n_{ijk} - s\right).$$

8. Anesthetists generally are not sent home without pay when there are no patients to care for. Typically an anesthetist who arrives to work a shift of a fixed number of hours (eg, an 8-hour shift) is paid for working the regular number of hours, even if the anesthetist's cases are finished within fewer hours (eg, within 6 hours rather than 8 hours). Then, considering characteristic #7, the cost on the jth work day of the ith period for having s anesthetists work the second shift equals s × (equivalent hourly salary) × (h_f − h_s + 1).

By combining characteristics 1 through 8, the cost of having s anesthetists working on the second shift of the jth work day of the ith period:

(1) $J_{ij}(s)$ = (equivalent hourly salary) ×

$$\sum_{k=h_s}^{h_f} \left(s + C_o \max\left(0, n_{ijk} - s\right)\right)$$

The cost (or benefit) of staffing the second shift with 1 less anesthetist for the ith period equals:

$$(2) \qquad \sum_{j=1}^{N_{di}} \left(J_{ij}(s) - J_{ij}(s+1)\right).$$

By using equation 2, we can increase incrementally the number of anesthetists working the second shift to determine for which number the expected labor costs are the lowest.

Example

Data were obtained from the tertiary surgical suite at the University of Iowa, Iowa City, Iowa, for all regularly scheduled work days between the first day with reliable data (January 1, 1994) to the date that we started the analysis (October 2, 1998). This interval provided us with N_p = 62 four-week periods that we could use to test our graphical statistical method.

Referring to equation 2, the average daily cost during the ith 4-week period caused by having 1 instead of 2 anesthetists scheduled to work the second shift equals:

$$\left(\sum_{j=1}^{N_{di}} \left(J_{ij}(1) - J_{ij}(2)\right)\right) \Big/ N_{di}.$$

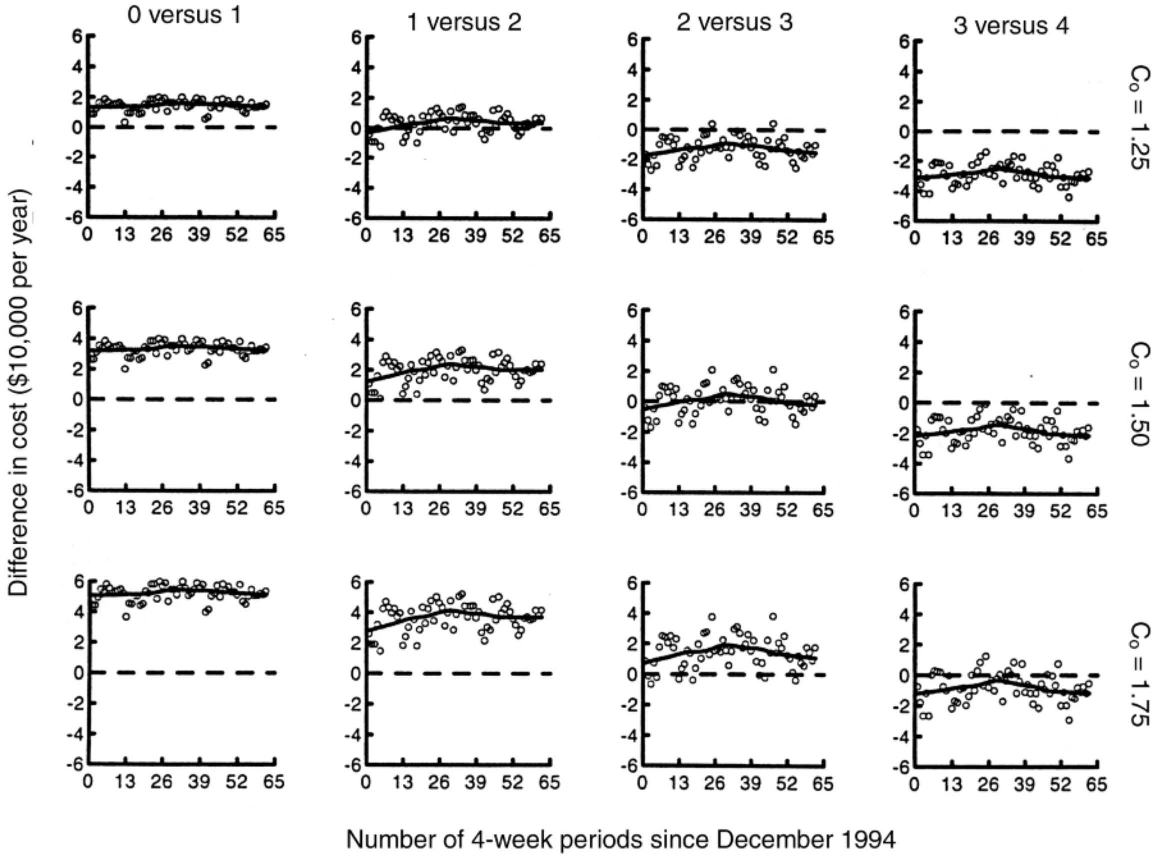
To provide a financial perspective, we consider an annual wage of $80,000 and an 8-hour shift running from 3 to 11 PM. Then, on an annualized basis, the cost equals ($80,000 per year) × (8 hours each day)$^{-1}$ ×

$$\left(\sum_{j=1}^{N_{di}} \left(J_{ij}(1) - J_{ij}(2)\right)\right) \Big/ N_{di}.$$

The same argument applies to having 0 versus 1, 2 versus 3, or 3 versus 4 anesthetists.

The results are given in Figure 1. Each circle represents 1 of the 4-week periods: i = 1 to N_p. The first data point (at a value of 1 on the horizontal axis) has a date of January 1994. Tick marks on the horizontal axis are spaced at December 1994 (0 four-week periods since December 1994), December 1995 (13 four-week periods since December 1994), and so on. Tick marks along the vertical axis are spaced in $10,000 increments (eg, a "2" refers to $20,000 per year). Reviewing the smoothed

Figure 1. **Anesthetist scheduling using data from the University of Iowa, Iowa City**

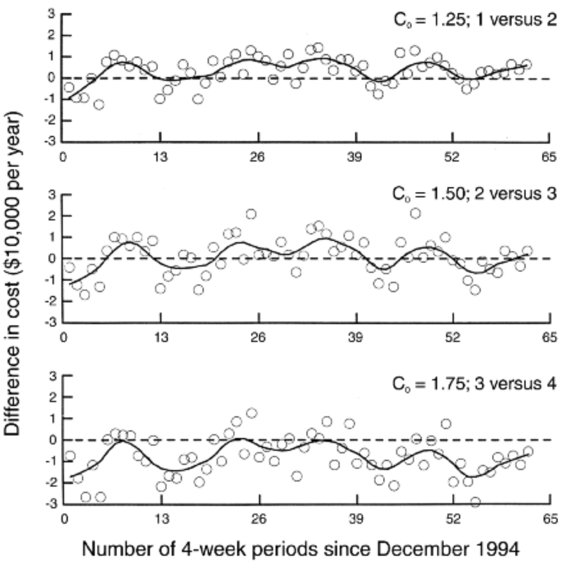


Data are shown for consecutive 4-week periods. The first data point (at a value of 1 on the horizontal axis) has a date of January 1994. Tick marks are provided on the horizontal axis at successive Decembers (eg, 0 specifies December 1994, and 26 specifies December 1996). Tick marks along the vertical axis are spaced in $10,000 increments. Each point gives the average daily cost during a 4-week period caused by 0 instead of 1, 1 instead of 2, 2 instead of 3, or 3 instead of 4 anesthetists scheduled to work the second shift. The financial perspective is added by assuming an annual wage including benefits of $80,000 and an 8-hour second shift starting at 3 PM. The smooth curve was drawn[5] using the Loess algorithm[6] with a tension of 0.5.

curves, there do not seem to be any trends over time. Referring to the upper row, first column, given an overtime valuation of C_O = 1.25, if no anesthetist was scheduled to work during the second shift, the cost would be approximately $20,000 per year higher than if 1 anesthetist were scheduled to work the second shift. This result implies that if no anesthetist were scheduled to work the second shift, frequently anesthetists working the first shift would have to remain working past the end of the first shift. Referring to the upper row, second column, there seems to be no difference in cost between having 1 or 2 anesthetists scheduled to work the second shift. The cost associated with having anesthetists from the first shift remain until the cases in their ORs finish is balanced by the risk of having 1 or 2 anesthetists scheduled to work the second shift and yet have no patients to care for during some hours of the second shift.

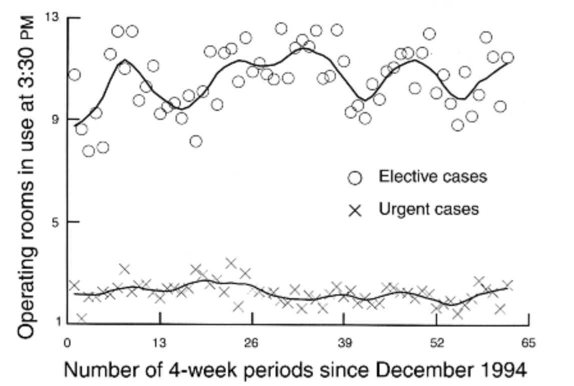
Based on Figure 1, upper row, second column; middle row, third column; and lower row, fourth column; for valuations of C_O = 1.25, 1.50, or 1.75, then 1 or 2, 2 or 3, or 3 or 4 anesthetists would be reasonable choices to minimize costs. Figure 2 presents data from these 3 panels in more detail. Tick marks are provided on the horizontal axis at December 1994, December 1995, and so on. Seasonal variation is observed. Each winter,

Figure 2. Detailed look at results from Figure 1



The upper row, second column of Figure 1 is plotted in the upper row of Figure 2. The middle row, third column of Figure 1 is plotted in the middle row of Figure 2. The lower row, fourth column of Figure 1 is plotted in the lower row of Figure 3. The first data point (at a value of 1 on the horizontal axis) has a date of January 1994. Tick marks are provided on the horizontal axis at successive Decembers (eg, 0 specifies December 1994, and 26 specifies December 1996). Tick marks along the vertical axis are spaced in $10,000 increments. The smooth curve was drawn[5] using the Loess algorithm[6] with a tension of 0.15.

Figure 3. Graphical analysis of the seasonality observed in Figure 2



The first data point (at a value of 1 on the horizontal axis) has a date of January 1994. Tick marks are provided on the horizontal axis at successive Decembers (eg, 0 specifies December 1994, and 26 specifies December 1996). Tick marks along the vertical axis are spaced in $10,000 increments. The number of rooms running at 3:30 pm at the University of Iowa, Iowa City, is used for explanatory purposes. A case was considered to be "elective" or "urgent" if it was scheduled before or within 24 hours of the day of surgery, respectively. The smooth curve was drawn[5] using the Loess algorithm[6] with a tension of 0.15.

fewer anesthetists are needed. Each summer, more anesthetists are needed. Further illustration and explanation is provided for interested readers in Figure 3.

We use C_o = 1.25 to represent salaried anesthetists (wage C_o = 1.00) with additional valuation (0.25) provided to indicate that when working long hours, anesthetists eventually will leave the anesthesia group. From the upper panel of Figure 2, 1 anesthetist probably should be scheduled to work the second shift during the winters, 2 anesthetists during the summers, and 1 or 2 during the fall and spring.

If anesthetists are hourly employees, they must receive overtime at time-and-a-half. If this were the situation, and if anesthetists are not leaving the first shift and reporting that their hours are too long, then C_o = 1.50 may be appropriate. From the middle panel of Figure 2, a reasonable staffing plan would be to employ 2 anesthetists to work the second shift during winters, 2 or 3 during fall and spring, and 3 for the summers.

A valuation of C_o = 1.75 could be used to indicate hourly employees who despite receiving an overtime wage are leaving the first shift citing too many hours worked. From the lower panel of Figure 2, a staffing plan would be to employ 3 anesthetists to work the second shift during winters and 4 to work during summers.

Discussion

Our analysis considers all of the anesthetists working the second shift to start working at the same time (eg, 3 PM). There are a couple of scenarios for which some of the anesthetists working a second shift might start working earlier. For example, if 2 anesthetists were scheduled to work during the second shift, 1 may be scheduled to work from 1 to 9 PM and 1 from 3 to 11 PM. These 2 scenarios arise if, at a surgical suite, characteristically there are more anesthetists working at the end of the second shift than there are patients to be cared for (ie, ORs running). To incorporate such subtleties into the mathematics adds greatly to the complexity. We therefore rely on a qualitative understanding of the concepts.

1. One or more of the anesthetists working the first shift may have other work activities that they perform when they are relieved from ORs (eg, managerial activities). There may be a financial advantage for some of the anesthetists working the second shift to start 1 or 2 hours earlier to relieve these anesthetists before the end of the first shift.

2. Relieving anesthetists before the end of the first shift does not decrease overtime payment, because anesthetists generally have a minimum number of paid hours of work each day. However, we included overtime valuations of $C_O = 1.25$ to indicate salaried anesthetists who are leaving the first shift citing too many hours worked. Likewise, we considered overtime valuations of $C_O = 1.75$ to indicate hourly employees who despite receiving an overtime wage of time-and-a-half report working too many hours. Scheduling some of the anesthetists working the second shift to start a few hours earlier may help retention of anesthetists working the first shift who are working more hours than they would prefer.

Some surgical suites schedule surgical nurses with multiple overlapping shifts throughout the day, meaning a mixture of 4-, 6-, 8-, 10-, and/or 12-hour shifts. Such strategies can decrease labor costs, provided (1) the surgical nurses have no minimum number of hours of paid work each day and are sent home without pay when their cases finish, and (2) some surgical nurses work short (eg, 4-hour) shifts on some days. Although our method could be used for such situations, these 2 requirements are atypical for anesthetists.

In this article, we described a graphical method we developed to determine staffing requirements for a second shift of anesthetists to minimize labor costs. Cases routinely run late in surgical suites for 1 of 3 reasons. First, some surgical suites plan on performing each day all of the cases submitted by the surgeons. Strum et al[7] showed how to determine how many first-shift ORs to allocate to each surgical group at such surgical suites to minimize labor costs. Second, some surgical suites have urgent surgical cases for which the patient may be harmed if he or she must wait until the next regularly scheduled OR day for the case to be performed. Dexter et al[8] showed how to sequence these urgent surgical cases to perform them in as few ORs as possible to minimize labor costs. Third, case duration for elective cases consistently may be underestimated. Dexter et al[9] found that the use in scheduling of the mean of the durations of previous cases of the same scheduled procedure type by the same surgeon will minimize labor costs.

In conclusion, we developed a graphical statistical method to assist an anesthesia group to decide how many anesthetists the group should plan on working during a second shift to minimize labor costs. We also provided some recommendations on how to use the method.

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