Statistical method using operating room information system data to determine anesthetist weekend call requirements

FRANKLIN DEXTER, MD, PhD
Iowa City, Iowa
ALEX MACARIO, MD, MBA
Stanford, California
RODNEY D. TRAUB, PhD
Fargo, North Dakota

We present a statistical method that uses data from surgical services information systems to determine the minimum number of anesthetists to be scheduled for weekend call in an operating room suite. The staffing coverage is predicted that provides for sufficient anesthetists to cover each hour of a 24-hour weekend period, while satisfying a specified risk for being understaffed. The statistical method incorporates shifts of varying start times and durations, as well as historical weekend operating room caseload data. By using this method to schedule weekend staff, an anesthesia group can assure as few anesthetists are on call as possible, and for as few hours as possible, while maintaining the level of risk of understaffing that the anesthesia group is willing to accept. An anesthesia group also can use the method to calculate its risk of being understaffed in the surgical suite based on its existing weekend staffing plan.

Key words: Anesthetist staffing, operating room economics, operating room information system, operating room management, staff scheduling.

Introduction

If too few anesthetists are on call on weekends, there may not be enough anesthetists to start urgent operating room (OR) cases in a timely manner. On the other hand, having too many anesthetists on call increases the call burden unnecessarily. Frequent call may increase costs if additional anesthetists need to be hired or if anesthetists are dissatisfied with the anesthesia group's workload and leave the group.

Currently, anesthesia groups may determine the number of anesthetists to schedule for weekend call based on the perception of how busy the weekend workload is likely to be. For example, if anesthetists perceive the weekend OR caseload to be high compared with the number of anesthetists on call, additional anesthetists may be added to future weekend call schedules. Alternatively, anesthesia groups may attempt to optimize staffing by analyzing statistically historical OR caseload data to adjust the lengths of shifts (eg, 8- or 24-hour shifts) or the times when shifts begin and end (eg, 7 AM or 9 AM).

The goal of the present study was to apply an existing statistical method to determine the minimum number of anesthetists to be scheduled for weekend call and the shifts that the anesthetists would work, while providing for sufficient staff to care for patients in a surgical suite. For purposes of our analysis, we considered that the staffing can address 2 objectives for an anesthesia group. The first objective that an anesthesia group may have is to minimize the total number of anesthetists on call (eg, if anesthetists are salaried or group partners). The second objective that an anesthesia group may have is to minimize the total number of staffed hours (eg, if anesthetists are paid an hourly wage). The analysis applies equally to whichever of these 2 objectives an anesthesia group chooses to use. The analysis applies equally to "in-house" call or call "from home."

For the present study, we used weekend data from the University of Iowa, Iowa City, to illustrate how to use our statistical method. The data needed to determine weekend staffing using the statistical method are the previous numbers of ORs running (that have patients inside the OR) at every hour in the specified 24-hour period. By using these data, one can calculate the number of anesthetists and total hours of anesthesia coverage that will be needed in the surgical suite for a future 24-hour period.

Description of the statistical method

The statistical method relies on 3 input data elements:

(1) the risk of being understaffed that an anesthesia group can tolerate,

(2) the duration and start times of shifts that anesthetists in the group consider to be desirable, and

(3) the historical weekend OR caseload activity (eg, from an OR information system).

These 3 data elements are described in the next 3 sections. Calculations using the 3 data elements are given in the fourth section. Data used in an example are described in the last paragraph of each of the 4 sections. The example is given in the fifth section.

■ *Risk of being understaffed.* The statistical method that we describe is based on having enough anesthetists on call to care for all the day's patients for a predetermined percentage of 24-hour periods. The anesthesia group determines the percentage of 24-hour periods (ie, risk) that the group can accept being understaffed for at least part of the 24-hour period. The level of risk that an anesthesia group can tolerate may depend on several factors, including the types of cases performed during weekends (ie, elective cases vs trauma cases). Ideally, the risk of being understaffed would be much less than 1%. However, this objective is not realistic, as it would require many anesthetists to be on call. In this situation, the anesthetists on call often would not be involved in patient care. In contrast, a risk of being understaffed for at least 1 hour on 10% or 20% of the 24-hour periods may not provide adequate anesthetist availability for patients and surgeons.

An anesthesia group needs to have a plan in place to care for patients when the group is understaffed. Characteristically, the cases would be sequenced and performed as soon as possible. The OR information system can be programmed to assist in optimizing the sequence of pending (urgent) cases.[1]

For purposes of the example that we use to illustrate use of the statistical method, we choose a 5% risk of an anesthesia group being understaffed. This choice implies that on 2 to 3 Saturdays a year, the group will be understaffed for at least part of the 24-hour period.

■ *Duration and start times of shifts.* The shifts that anesthetists on call work can overlap. For example, some anesthetists may be on call for 24 hours from 7 AM Saturday to 7 AM Sunday. Others may work Saturday from 7 AM to 7 PM. An analysis of historical surgical suite activity may suggest that 3 anesthetists need to be on call Saturday from 7 AM to 9 AM, 1 anesthetist from 9 AM to 10 AM, and 2 anesthetists from 10 AM to 11 AM. Such a staffing decision may be impractical. Therefore, the statistical method to evaluate weekend staffing needs to incorporate shift start times and durations that the anesthetists in the anesthesia group consider desirable. These start times and durations can be chosen, for example, by surveying the anesthetists on the hours they would prefer to work.

For our example, we considered anesthesia staffing for a weekend period that is 24 hours long and runs from 7 AM Saturday morning to 7 AM Sunday morning. We evaluated 14 shifts that anesthetists may consider:

1. Not working at all that day
2. 24-hour shift beginning at 7 AM
3. 8-hour shift beginning at 7 AM
4. 10-hour shift beginning at 7 AM
5. 12-hour shift beginning at 7 AM
6. 14-hour shift beginning at 7 AM
7. 16-hour shift beginning at 7 AM
8. 10-hour shift beginning at 9 AM
9. 12-hour shift beginning at 9 AM
10. 14-hour shift beginning at 9 AM
11. 22-hour shift beginning at 9 AM
12. 8-hour shift beginning at 3 PM
13. 16-hour shift beginning at 3 PM
14. 12-hour shift beginning at 7 PM

The statistical method we describe could include any other combination of the myriad possible different shifts for their suitability in providing minimum numbers of anesthetists or hours of anesthetists to care for patients in the surgical suite.

■ *Weekend caseload activity.* Data used by the statistical method include the maximum number of ORs running each hour of each day of the period of interest. In the present study, we considered periods that are 24 hours long to correspond to a weekend day. Data are collected for each of the 24 hours of the period of interest over consecutive weeks. For example, we would include data from each hour between 7 AM Saturday, January 1, and 7 AM Sunday, January 2. We also would include data from each hour between 7 am Saturday, January 8, and 7 AM Sunday, January 9. However, we would skip data from 7 AM Sunday, January 2, to 7 AM Saturday, January 8. The data consist of the number of rooms being used during that hour. For example, between 3 PM and 4 PM on 4 consecutive Saturdays there could be 1, 3, 4, and 2 operating rooms with cases.

The number of 24-hour periods with data (N) should contain as many years of reliable data as available. As explained in the Appendix, most anesthesia groups will require at least N=52 weeks or 1 year of data to determine how many anesthetists to have on call. The smaller the risk of being understaffed that the anesthesia group is willing to accept, the larger the minimum sample size or number of 24-hour periods of data (N) required to calculate a staffing decision.

For our example, data were obtained from the University of Iowa for the 248 twenty-four hour periods from 7 am Saturday to 7 am Sunday between January 1, 1994 and October 3, 1998. We have not printed these 5,952 (248 × 24) numbers. So that readers can appreciate that the results given in our example are reasonable, we include summary information. Among the N = 248 twenty-four hour periods of data used to create the example, the 10th, 25th, 50th, 75th, 90th, 95th, and 99th percentiles for the maximum number of ORs running each 24-hour period equaled 0, 0, 1, 2, 2, 3, and 3, respectively.

■ *Calculations.* Each of the possible staffing decisions is a combination of the shifts that the anesthetists in the anesthesia group consider desirable. The final step of the statistical method is the calculation of all possible staffing decisions from the durations and start times of the different shifts. This calculation provides the number of anesthetists who would be scheduled to work at each hour of the 24-hour period of interest. The number of anesthetists who would be scheduled to work each hour then is compared with the number of anesthetists who were needed at that hour during the N 24-hour periods of historical data. The number of 24-hour periods among the N previous periods during which the surgical suite would have been understaffed at any time during the 24-hour period is counted. If the number of understaffed periods is larger than a cutoff value U (explained in the next paragraph), that staffing decision or combination of shifts is no longer considered. For each combination of shifts satisfying the requirement that the number of understaffed periods equals U or less, the total number of staff required for the 24-hour period and the total number of staff hours during the 24-hour period are calculated. The recommended staffing decision is the combination of shifts with the least total number of staff required for the 24-hour period and/or total number of staff hours during the 24-hour period.

The cutoff value of U, referred to in the preceding paragraph, is the maximum number of historical 24-hour periods for which a proposed staffing decision *could* have (not would have) provided an inadequate number of anesthetists for at least part of the 24-hour period while maintaining the level of risk that the anesthesia group considers acceptable. The 2 numbers used to calculate U are the numbers of 24-hour periods of historical data available from the surgical suite's information system (N) and the level of risk in being understaffed (R) that the anesthesia group is willing to accept. The statistical theory relies on calculating a $100(1-\alpha)\%$ upper confidence bound for the percentage R of understaffed 24-hour periods based on the number of understaffed periods U among the N 24-hour periods of observations. Equations are given in the Appendix.

The statistical method considers differences in workload from hour to hour within the 24-hour period of interest, but not week to week. The assumption of the statistical method is that there are no differences among weeks in the expected workload of the surgical suite at each of the hours of the 24-hour period. In the "Discussion" section, we consider scenarios for which this assumption would likely not be satisfied. We describe in the Appendix how we tested the validity of this assumption for the example created using data from the University of Iowa.

For our example, $\alpha=0.05$, N=248 previous weeks of data, and the minimum acceptable risk for being understaffed R=5%. From the equation in the Appendix, the smallest number of periods (U) among the N periods of observations for which a proposed staffing plan could have provided too few anesthetists to run the operating rooms equals U=6.

Example of using the statistical method to obtain the optimal staffing decision

We illustrate use of the statistical method to obtain the optimal staffing decision in a surgical suite requiring several anesthetists on call. Data used in this example are described in the last paragraph of each of the previous 4 sections.

All possible staffing decisions that satisfied the requirement for a risk R ≤ 5% (less than 5% of 24-hour periods would be understaffed) required a minimum total of 4 anesthetists for call for at least part of the 24-hour period. Since all acceptable staffing decisions had the same total number of anesthetists, the logical choice was to choose the staffing decision that minimized the total staffing hours. For the example created using data from the University of Iowa, the staffing decision that minimized the total staffing hours and satisfied minimum staffing requirements was the following: 2 of the 4 anesthetists work 24-hour shifts, 1 of the 4 anesthetists works from 7 AM to 9 PM, and 1 of the 4 anesthetists works from 7 PM to 7 AM. Compared with having all 4 of the anesthetists working 24-hour shifts, the optimal staffing decision decreased the total number of staffed hours by 22 hours [4 × 24 - (2 × 24 + 14 + 12)].

With this staffing combination, four 24-hour periods had understaffed hours (less than U = 6). That is, using this staffing decision, on 4 of 248 previous Saturdays, the surgical suite would have been understaffed. The observed risk equaled 4 ÷ 248 or 1.6% (upper 95% confidence bound = 3.6%).

In comparison, we considered the results if the anesthesia group were to have 3 anesthetists work 24-hour shifts. Then, statistically, we would expect eight 24-hour periods to have understaffed hours (more than U = 6). The observed risk would equal 8 ÷ 248 or 3.2% (upper 95% confidence bound = 5.7%, which is larger than the specified risk of 5% that would be achieved by U = 6).

The decision to require a risk R ≤ 5% for being understaffed for some part of a 24-hour period resulted in a lot of downtime (anesthetists available but not actively involved in patient care). By using the minimum anesthetist staffing decision described above (ie, 2 of the 4 anesthetists work 24-hour shifts, 1 of the 4 anesthetists works from 7 AM to 9 PM, and 1 of the 4 anesthetists works from 7 PM to 7 AM), review of the data revealed that we would expect anesthetists to have cases for 35% of the 74 hours they are on call. If, instead of the optimal staffing decision, 4 anesthetists were scheduled to work 24-hour shifts, patients would have been in the staffed operating rooms for 27% of the hours that the anesthetists were on call.

Discussion

We describe how a traditional statistical method can be used to analyze historical caseload data stored in OR information systems to determine the minimum number of anesthetists to be scheduled for call. This data-driven method may be particularly useful for anesthesia groups that want to confirm that their current weekend staffing assures as few anesthetists are on call as is possible, and for as few hours as is possible, while maintaining the level of risk of understaffing that the anesthesia group is willing to accept.

From the analysis we describe, an anesthesia group can achieve quantitative knowledge about its risk of being understaffed to care for patients in a surgical suite. Performance of a quantitative risk assessment for being understaffed can be a useful part of an anesthesia group's risk-management program.

These reasons for using our statistical method are financial. Therefore, we think that an anesthesia group should decide whether to implement our statistical method by balancing its expected cost savings with the cost of implementation. To put our results into a budgetary perspective, we consider our example. In the example, if the anesthesia group originally scheduled 4 anesthetists each to do a 24-hour shift, then the optimal staffing decision would decrease its total number of staffed hours by 22 hours. If the anesthetists are hourly employees, the hours are overtime, and the hourly overtime cost is $60 [1.5 × $80,000 per year ÷ (50 weeks per year × 40 hours per week)], then the statistical method would decrease labor costs by $68,640 per year. The decrease in labor costs from using the statistical method will be the largest for anesthesia groups that have many anesthetists on weekend call who are doing urgent or emergency cases, resulting in a variable workload.

The potential decrease in staffing costs from using our statistical method (ie, anesthesia group makes more money) needs to be balanced against the cost of implementing the statistical method using a computer spreadsheet (ie, anesthesia group loses money by implementing our method). Our approach was to use a Microsoft Excel spreadsheet (Microsoft, Redmond, Wash) with 24 columns (1 for each hour) and N rows. Each cell of the spreadsheet corresponded to the maximum number of operating rooms occupied during each hour of each 24-hour period. This information was read by Excel from a file created by the OR information system. We performed the analysis given in the example by writing 69 lines of computer code in Microsoft Excel Visual Basic, which comes as part of Excel. Since an anesthesia group considering using our method will work in a surgical suite that already has an OR information system and will already have a spreadsheet program, the cost of implementing our method should be the salary for 1 or 2 days of a consulting statistician, hospital engineer, or management scientist.

The example shows that a decision to require a risk $R \le 5\%$ for being understaffed for some part of a 24-hour period can result in a lot of time for which anesthetists are on call but not actively involved in patient care. The trade-off between downtime and availability is well known to anesthesia groups. Some anesthesia groups may practice in hospitals wherein negotiations are more successful when supplemented by data and analysis. Because our method provides for the minimum total number of anesthetists (if salaried) or total hours of anesthesia coverage (if paid hourly) as is theoretically possible, such anesthesia groups may find our method to be useful as they negotiate with hospitals about the costs for providing 24-hour coverage.

The problem of determining on which weekend days each staff member is to work[2,3] (eg, "Frank" and "Alex" work next Saturday) is not considered in this article. In addition, our statistical method is unlikely to apply to determining staffing requirements during regularly scheduled OR days.[4]

The statistical method for determining minimal anesthetist weekend staffing requirements assumes that the risk for having too few anesthetists on call is unchanging among consecutive weekend 24-hour periods. We consider in the Appendix how to test this assumption, because it may not hold under several circumstances. First, weekend caseload may be influenced by the number of anesthetists on call. If in the past there were not enough OR nurses or anesthetists to meet the surgical suite's policy for performing urgent cases on weekends, then data from that period should not be included in the analysis. Statistical analysis of weekend anesthetist staffing makes sense only provided there is an unchanging policy for performing weekend cases. Second, seasonal variation in workload may exist. Anesthesia groups located, for example, at ski resort communities with higher workload during the winter may need to consider staffing for the 24-hour periods from the busy season separately from the 24-hour periods from the remainder of the year. Third, there may be a trend upward or downward in OR cases on weekends, as might occur with a new hospital contract for trauma care. Then, only the most recent data should be used in making a staffing decision.

Appendix — Mathematical details for the practitioner implementing (programming) the statistical method

We considered a $100(1-\alpha)\%$ upper confidence bound for the percentage R of understaffed 24-hour periods based on the number of understaffed periods U among the N periods of observations.[5] The appropriate value of U is the smallest whole number satisfying the relationship:

$$R \le 100/[1+(N-U)/((U+1)F(1-\alpha, 2U+2, 2N-2U))].$$

In the equation, $F(1-\alpha, 2U+2, 2N-2U)$ refers to the F distribution with $(2U + 2)$ and $(2N - 2U)$ degrees of freedom. Use of the equation requires looking up a value for the F distribution (from a textbook or statistics program). We found the value of U for our example by hand, using a trial and error approach.

The equation specifies the minimum acceptable N. Conceptually, since $U \ge 1$, N has to be at least equal to $100/R$, but will be larger due to random error. Any value for α could be used that an anesthesia group considers to be appropriate. For example, substituting $\alpha = 0.05$ into the equation, the 95% upper confidence bound for the percentage R of understaffed periods is less than 5% based on there being no (ie, U = 0) understaffed periods achieved by a proposed staffing decision among N = 59 twenty-four hour periods of observations. This result explains our observation that most anesthesia groups will need at least N=52 weeks or 1 year of data to determine the optimal staffing decision when using a risk for having a sufficient number of anesthetists on call that the group will consider to be acceptable.

Most anesthesia groups have sufficiently few anesthetists on weekend call that the process of considering all possible combinations of shifts will not be formidable computationally. Analysis of the example using Microsoft Excel Visual Basic code took 3 seconds of execution time on a 400 MHz Intel Pentium II microprocessor (Intel Corporation, Santa Clara, Calif). We considered 14 different shifts and 4 different anesthetists, providing 2,380 combinations of anesthetists and shifts. There were N=248 observations. Therefore, 24 × 248 × 2,380 = 14,165,760 comparisons could have been performed between the number of operating rooms running each hour and the proposed number of anesthetists on call each hour. However, many fewer comparisons were required. Once each combination of shifts had been created, the computer program evaluated the potential staffing decision's total number of anesthetists and total hours of staffing. These values were compared with the total number of anesthetists and hours of staffing from the staffing decisions that previously had been found to satisfy the staffing criterion, if there had been any. Unless the new potential staffing decision provided for either a smaller number of anesthetists on call or total hours of anesthetists on call, the potential staffing decision could not offer a staffing advantage relative to previously considered acceptable staffing decisions, and, as such, it was not compared with the observed number of ORs running each hour.

The statistical analysis assumes that there are no differences in staffing requirements among consecutive weekend 24-hour periods in the risk for having too few anesthetists on call. We provide an example of how we evaluated this assumption using the data from the University of Iowa. With the optimal staffing decision, 4 of the N=248 twenty-four hour periods had at least 1 hour with inadequate staffing. We reviewed these four 24-hour periods for which the recommended staffing pattern was inadequate. First, the 24-hour periods with inadequate staffing were the 4th, 22nd, 120th, and 188th of 248 twenty-four hour periods, suggesting that there was no trend over time. Second, the Runs Test[6] was used to evaluate the number of 24-hour weekend periods with adequate staffing between successive 24-hour weekend periods with inadequate staffing to test the null hypothesis[6] that every 24-hour period had an equal probability of adequate staffing. The probability for the observed numbers of 24-hour periods with adequate staffing between 24-hour periods with inadequate staffing (17 days = 22 − 4 − 1, 97 days = 120 − 22 − 1, and 67 days = 188 − 120 − 1) equaled P = .92 (StatXact 3 for Windows, Cambridge, Mass). Third, the dates for the four 24-hour periods with at least 1 understaffed hour were January 22, 1994; May 28, 1994; April 20, 1996; and August 9, 1997, suggesting that no one season predominated, and that the dates did not correspond to holidays.

REFERENCES

(1) Dexter F, Macario A, Traub RD. Optimal sequencing of urgent surgical cases — scheduling cases using operating room information systems. *J Clin Monit Comput.* 1999;15:153-162.

(2) Arthur JL, Ravindran A. A multiple objective nurse scheduling model. *AIIE Transactions.* 1981;13:55-60.

(3) Bradley DJ, Martin JB. Continuous personnel scheduling algorithms: a literature review. *J Soc Health Syst.* 1990;2:8-23.

(4) Dexter F, Traub RD. Determining staffing requirements for a second shift of anesthetists by graphical analysis of data from operating room information systems. *AANA J.* 2000;68:31-36.

(5) Hahn GJ, Meeker WQ. *Statistical Intervals: A Guide for Practitioners.* New York, NY: John Wiley & Sons, Inc; 1991:104.

(6) Farnum NR, Stanton LW. *Quantitative Forecasting Methods.* Boston, Mass: PWS-Kent Publishing Co; 1989:57.

AUTHORS

Franklin Dexter, MD, PhD, is associate professor in the Department of Anesthesia at the University of Iowa, Iowa City, Iowa. He is employed by the University of Iowa, in part as a consultant to anesthesia groups, companies, and hospitals.

Alex Macario, MD, MBA, is assistant professor in the Departments of Anesthesia & Health Policy and Research at Stanford University, Stanford, Calif.

Rodney D. Traub, PhD, is associate professor in the College of Business at North Dakota State University, Fargo, ND.