Modeling daily veterinary anesthetist patient care hours and probabilities of exceeding critical thresholds

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OBJECTIVE

Use a referral dental clinic model to study how to calculate accurate 95% upper confidence limits for probabilities of workloads (total case duration, including turnover time) exceeding allocated times.

ANIMALS

Dogs and cats undergoing dental treatments.

METHODS

Managerial data (procedure date and duration) collected over 44 consecutive operative workdays were used to calculate the daily anesthetist workload. Workloads were compared with a normal distribution using the Shapiro-Wilk test, serial correlation was examined by runs test, and comparisons among weekdays were made using the Kruskal-Wallis test. The 95% confidence limits for normally distributed workloads exceeding allocated times were estimated with a generalized pivotal quantity. The impact of a number of procedures was assessed with scatterplots, Pearson linear correlation coefficients, and multivariable linear regression.

RESULTS

Mean anesthetist’s workload was normally distributed (Shapiro-Wilk $P = .25$), without serial correlation ($P = .45$), and without significant differences among weekdays ($P = .52$). Daily workload, mean 9.39 hours and SD 3.06 hours, had 95% upper confidence limit of 4.47% for the probability that exceeding 16 hours (ie, 8 hours per each of 2 tables). There was a strong positive correlation between daily workload and the end of the workday ($r = .85$), significantly larger than the correlation between the end of the workday and the number of procedures ($r = .64, P < .0001$).

CLINICAL RELEVANCE

There are multiple managerial applications in veterinary anesthesia wherein the problem is to estimate risks of exceeding thresholds of workload, including the costs of hiring a locum, scheduling unplanned add-on cases, planning for late discharge of surgical patients to owners, and coordinating anesthetist breaks.

Keywords: operating room management, case duration, case scheduling, economics, operational research

Operating room management science is integral to increasing productivity, letting the same personnel care for more patients safely.1 Recent bibliometric study2 showed that among the 11 authors who each have contributed to at least 1% of the field’s publications, 9 of the 11 investigators were human anesthetists and the other 2 investigators did their mathematical studies with anesthetists as coauthors. However, there was only 1 study2 in veterinary medicine that considered predicting treatment duration.

We consider a veterinary anesthetist in Canada caring for small animal patients undergoing dental treatment. The veterinary anesthetist both directly cares for some patients and supervises veterinary technicians. Consequently, the anesthetist often cares for 2 patients at the same time. One question we consider is how best to schedule cases for each working day while assuring maximum efficiency of the use of the anesthetist.3 The veterinary anesthesia management problem differs considerably from that of human anesthetists in Canada. The human anesthetists care for 1 patient at a time, with no (literally zero) overlap between induction and emergence from general anesthesia. The veterinary clinic also has 1 anesthetist, making it important not only what
choice of the available hours maximizes the efficiency of the anesthetist but also ensures a low probability of the anesthetist and technicians working late.

The principal question being studied in the current article is how to calculate 95% upper confidence limits for probabilities of workloads exceeding the allocated times, where allocated time refers to the hours into which cases would be scheduled, such as 8 hours (Table 1). Earlier studies, all for human operating rooms in the US, have shown that the daily workload has a serial correlation.10–12 That is, if one day is full, patients are scheduled for the next available date. Such correlation has made it impractical to assess statistical methods for the probabilities of exceeding allocated time. We expected that this would be different for the veterinary dentistry clinic, making the dataset suitable for the study of the statistical methods. A lack of serial correlation was expected because radiographs to forecast surgical (dental) time were performed after the patient was anesthetized, immediately before dental treatment. Therefore, not only was each patient (ie, case) scheduled for the same estimated duration, but this was proper managerially and thus generalizable.

**Methods**

Managerial data were obtained from the electronic health record for each patient: (1) date (eg, April 26, 2023); (2) binary variable of whether veterinary anesthetist cared for the patient (ie, “1”) or sedation only without anesthetist (ie, “0”); (3) time of premedication (eg, “08:18”); and (4) time of tracheal extubation or administration of sedation reversal (eg, “11:52”). From these data were calculated the daily anesthetist workload, meaning the total time of the veterinary anesthetist summed among patients from the time from premedication to extubation [eg, 10.17 hours on 1 date (1) by summing item (2) × (item (4) – item (3))] (Table 1). The sample sizes for all calculations in the Results are the number of days, not the number of patients.

**Table 1**—Operating room management definitions, adapted from Dexter et al.1

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocated time</td>
<td>The hours into which cases are scheduled, calculated months in advance, calculated based on minimizing the expected inefficiency of use of the anesthetist’s time.4,5 Results are the same from the perspective of the veterinary clinic overall.</td>
</tr>
<tr>
<td>Anesthesia duration</td>
<td>Measured as the time from the start of sedation until tracheal extubation. (Cost per hour of underutilized time) × (hours of underutilized time) + (cost per hour of overutilized time) × (hours of overutilized time).</td>
</tr>
<tr>
<td>Inefficiency of use of</td>
<td>(ie, not intuitive). At a typical relative cost of overutilized to underutilized time of 1.50 for overtime (ie, 1.5 X regular hourly cost), optimal staffing would be based on the 60th percentile of workload, where 0.60 = 1/(1 + 1/1.50).4–7 We apply also the common sensitivity analysis of the large relative cost ratio of 4.00, such that for 1 day in 5 (0.80) worked hours exceed allocated time.13 In other words, we substitute 0.80 into the critical percentile and make sure that the allocated time would be similar or identical.</td>
</tr>
<tr>
<td>time of anesthetists’</td>
<td>Workload minus the allocated time or zero if this difference is negative.4,5</td>
</tr>
<tr>
<td>Overutilized time</td>
<td>The cost of an hour of overutilized time divided by the cost of an hour of underutilized time. Ratios from 1.5 to 2.0 are considered typical for purposes of allocating time.8,9 For a relative cost ratio of 2.0, underutilized time occurs on 2/3 of days and overutilized time on 1/3 of days.4,5</td>
</tr>
<tr>
<td>Relative cost ratio</td>
<td>The process by which it is determined which anesthetist (or surgeon or technician) works which day. Group of surgeons who share anesthesiology and nursing team and schedule cases together (eg, “veterinary dentistry”).</td>
</tr>
<tr>
<td>Staff scheduling Surgical</td>
<td>Allocated time minus the workload, or zero if this value is negative. Total hours of cases and turnover times on each day.</td>
</tr>
<tr>
<td>service</td>
<td></td>
</tr>
</tbody>
</table>

### Analyses of daily anesthetist workload

We start by considering the allocated time that results in the smallest possible inefficiency of use of the veterinary anesthetist’s time (Table 1).1,4–9 We refer to the efficiency of the anesthetist’s time, but the methodology would be the same when considered from the perspective of the veterinary clinic overall. The allocated time is the hours into which cases will be scheduled (Table 1).1,7 This formulation was described mathematically by Strum et al9 in 1997. Typical choice options could be 2 patient tables for 7 hours, 2 for 8 hours, 1 for 8 hours, 1 for 10 hours, or 2 for 10 hours.5,6 No assumption needs to be specified about the probability distribution for the daily workload.4 The inefficiency of the use of operating room time is minimized based on the incidence of the workload exceeding a critical percentile.4–6 Different mathematical derivations are pages long (ie, not intuitive). At a typical relative cost of overutilized to underutilized time of 1.50 for overtime (ie, 1.5 X regular hourly cost), optimal staffing would be based on the 60th percentile of workload, where 0.60 = 1/(1 + 1/1.50).4–7 We apply also the common sensitivity analysis of the large relative cost ratio of 4.00, such that for 1 day in 5 (0.80) worked hours exceed allocated time.13 In other words, we substitute 0.80 into the critical percentile and make sure that the allocated time would be similar or identical.

Our sample size was chosen based on this preliminary analysis of the daily workload. The starting date was Monday, January 16, 2023. Procedure days that included sedation or general anesthesia were Mondays, Tuesdays, and Wednesdays. With cases through Wednesday, April 26, 2023, we expected n = 45, which would give 82.6% estimated statistical power to distinguish between 0.60 and 0.80 by a 1-sided binomial test with a type I error rate of 0.05 (Stata v18.0 power oneproportion command; StataCorp LLC).

**Statistical methods to evaluate assumptions of the management analyses**

As explained in the Introduction, the principal question being studied was how to calculate

2

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95% upper confidence limits for probabilities of workloads exceeding allocated times. Assuring the accuracy of coverage depends on the data lacking serial correlation among workdays.\textsuperscript{10-12} Correlation between the workload from one workday to the next was tested using the runs test (Stata \texttt{runtest} command). The runs test was performed with continuity correction, and values equal to the threshold were randomly assigned above and below. The comparison of workload (ie, total anesthetist time) among days of the week was performed using the Kruskal-Wallis test (Stata \texttt{kwallis} command). Test for the normal probability distribution was done graphically (Figure 1) and with the Shapiro-Wilk test (Stata \texttt{swilk} command). In addition, a normal quantile plot was produced (\texttt{qnorm} command).

Upper confidence limit of proportion of days with workload exceeding threshold

We seek a 95% upper confidence limit for the proportion of workdays with greater than 16 hours of anesthesia time. These are calculations related to engineering statistics as part of tolerance intervals.\textsuperscript{14} The available method has been to use the tables generated by Owen.\textsuperscript{14-16} The tables do not include many combinations of parameter values and the accuracy of their use with interpolation has been unknown, contributing to their lack of use in operating room management. In the current article, we follow the steps of Owen,\textsuperscript{15} get an answer, and then show a computational alternative with 1 long Office 365 Excel formula (Microsoft). We are not recommending to readers that Owen’s method be followed in practice. Rather, we apply it here to compare it with the computational approach. We deliberately use Owen’s notation, so interested readers can follow the steps in his article.\textsuperscript{15} We also include the page numbers from the Owen\textsuperscript{16} page because there are no equation numbers and the relevant equations are not listed in sequence in his article. Each of the mathematical steps is shown in the Results, because what we are examining are the steps themselves (ie, the steps are generalizable, not the specific data from 1 Canadian veterinary dental clinic).

Limitations of using the tables generated by Owen include that the nearest value needs to be used for the parameter $\lambda$ below, and the tables’ use generally cannot be automated. Our suggested alternative approach is to use a generalized pivotal quantity based on the properties of the normal distribution.\textsuperscript{16} This approach was described by Webb for use in testing projectile penetration of armor (ie, the thresholds refer to the thickness of armor).\textsuperscript{16} We present our implementation using Office 365 Excel.\textsuperscript{17}

Analyses of daily workload instead of anesthetics

We assessed the independent effect of knowing the number of anesthetics in addition to the daily workload. The veterinary dentistry clinic had 2 novel features making it a model system to investigate that association. Imaging was done once the patient was anesthetized. Procedures were all performed by the same team of 1 veterinary dentist and 1 veterinary anesthetist. Consequently, all cases were scheduled for the same amount of time. Thus, workload, in hours, and anesthetics were not associated with the scheduling process. This is unusual, wherein estimated anesthesia durations differ based on the scheduled procedure or combination of procedures.\textsuperscript{3} The unique situation of the veterinary dentistry practice was an advantage because, with all anesthetics reasonably having the same estimated anesthesia duration, the independent influence of the daily count of anesthetics of the service was accentuated.

To assess the independent effect of the count of anesthetics, the dependent variable studied was the time that the last anesthetic case was finished each day. We performed 3 similar analyses. First, we created scatterplots of workload versus the last case finished time and of cases versus the last case finished time. Second, we calculated Pearson linear correlation coefficients for each scatterplot (Stata \texttt{correlate} command) and then compared the Pearson correlations (\texttt{cortesti} command). Third, we used multivariable linear regression using ordinary least squares (Stata \texttt{regress} command).

Results

Analyses of daily anesthetist workload

There was only 2% (1/44) of the observed days with greater than 14 and 16 hours and 0% greater
than 18 or 20 hours (Figure 1). However, 52% (23/44) of the days had a workload that exceeded 10 hours. Therefore, the best allocated time choice (Table 1) based on a relative cost ratio of 1.50 would be either 2 tables for 7 hours, 2 for 8 hours, or in between, depending on the staff scheduling of the clinic team (Table 2). Because the observed 2% was less than 20%, the decision would be the same even if the large but often used relative cost ratio of 4.00 was applied, such that for 1 day in 5 worked hours exceed allocated time. Below, we start by treating the allocated time as 2 patient tables each for 8 hours. That means we consider the probability of the daily workload (ie, total hours of anesthetist time) of the veterinary dentistry service exceeding a threshold of 16 hours. We then repeat using 14 hours as sensitivity analysis.

### Evaluation of assumptions of the subsequent management analyses

Operating room workloads (and caseloads) frequently follow normal distributions4,12 based on median and \( P = .69 \) based on mean). The implication is that the probability distribution of workload was consistent with a normal distribution (Shapiro-Wilk test \( P = .25 \); Figure 1).

#### Upper confidence limit of proportion of days with workload exceeding threshold

There are \( n = 44 \) workdays. The anesthetist’s workload has sample mean \( \bar{x} = 9.39053 \) hours and sample SD \( s = 3.05693 \) hours, a coefficient of variation of 32.6%. (We are including multiple digits so readers can copy and paste from our article into Excel and get the same answers.) The threshold of interest is \( x^- = 16 \) hours. From pages 452 and 458 of the Owen15 article:

\[
f = n - 1 = 43
\]

\[
t = \sqrt{n} \left( x^- - \bar{x} \right) / s = (16 - 9.39053) / 3.05693 = 14.34193
\]

\[
y = (1 + t^2 / [2f])^{-1/2} = (1 + 14.34193^2 / [2 \times 43])^{-1/2} = 0.54298.
\]

\[
y = ty / \sqrt{2f} = 14.34193 \times 0.54298 / \sqrt{2 \times 43} = 0.8397
\]

The next step is to obtain \( \lambda \) from Table 6.1 generated by Owen.15 The closest choice is for \( f = 44, y = 0.60, \)

### Table 2—Example of empirical method for estimating optimal allocated time using relative cost ratio of 1.50 for overutilized versus underutilized time.

<table>
<thead>
<tr>
<th>Daily workload (h), n = 44 days</th>
<th>Underutilized time if allocate 14 hours</th>
<th>Overutilized time if allocate 14 hours</th>
<th>Inefficiency of use of time if allocate 14 hours</th>
<th>Inefficiency of use of time if allocate 16 hours</th>
<th>Overutilized time if allocate 20 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.37</td>
<td>0.00</td>
<td>2.37*</td>
<td>3.55</td>
<td>0.55</td>
<td>0</td>
</tr>
<tr>
<td>13.65</td>
<td>0.35</td>
<td>0</td>
<td>0.35</td>
<td>2.35</td>
<td>0</td>
</tr>
<tr>
<td>13.57</td>
<td>0.43</td>
<td>0</td>
<td>0.43</td>
<td>2.43</td>
<td>0</td>
</tr>
<tr>
<td>12.48</td>
<td>1.52</td>
<td>0</td>
<td>1.52</td>
<td>3.52</td>
<td>0</td>
</tr>
<tr>
<td>12.38</td>
<td>1.62</td>
<td>0</td>
<td>1.62</td>
<td>3.62</td>
<td>0</td>
</tr>
<tr>
<td>12.35</td>
<td>1.65</td>
<td>0</td>
<td>1.65</td>
<td>3.65</td>
<td>0</td>
</tr>
<tr>
<td>Full table is provided*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.48</td>
<td>8.52</td>
<td>0</td>
<td>8.52</td>
<td>10.52</td>
<td>0</td>
</tr>
<tr>
<td>5.17</td>
<td>8.83</td>
<td>0</td>
<td>8.83</td>
<td>10.83</td>
<td>0</td>
</tr>
<tr>
<td>4.63</td>
<td>9.37</td>
<td>0</td>
<td>9.37</td>
<td>11.37</td>
<td>0</td>
</tr>
<tr>
<td>4.13</td>
<td>9.87</td>
<td>0</td>
<td>9.87</td>
<td>11.87</td>
<td>0</td>
</tr>
<tr>
<td>3.63</td>
<td>10.37</td>
<td>0</td>
<td>10.37</td>
<td>12.37</td>
<td>0</td>
</tr>
<tr>
<td>2.70</td>
<td>11.30</td>
<td>0</td>
<td>11.30</td>
<td>13.30</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>4.74</td>
<td>6.63</td>
<td>10.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td>0.43</td>
<td>0.45</td>
<td>0.46</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Definitions are provided (Table 1). If the allocated times were for 14 hours (ie, 2 tables, each for 7 hours), then there would have been overutilized time for only 1 workday, shown in the top row. That single value of 2.37 hours = 16.37 from the first row first column, minus 14 hours. The last 2 rows show that the estimated mean and SEM from the fourth column equal 4.74 ± 0.43 hours. If the allocated times were instead 16 hours, then the inefficiency of use of anesthetist’s time would be significantly greater, sample mean of 6.63 ± 0.45 hours. The mean pairwise increase in the inefficiency of use of anesthetist’s time equals 1.89 ± 0.11 hours, depending on the staff scheduling of the clinic team.

*See (Supplementary Table S1) for full table and significance.
and \( y = 0.8 \) with the listed \( \lambda = 1.66842 \), on page 456. (Note that Table 6.1 in the Owen article extends across multiple pages, such that the page number is relevant.) Continuing, from page 458:

\[
\delta = t - \lambda / y = 14.34193 - 1.66842 / 0.54298 = 11.269
\]

\[
K_9 = \delta / \sqrt{n} = 11.269 / \sqrt{44} = 1.6989
\]

(We again continue to use the Owen notation including the \( L \) for lower bound less than a threshold, although we consider the upper bound for the incidence greater than a threshold.) The inverse of the standard normal distribution using \( K_9 \) equals 0.9553. The corresponding Excel formula for the calculation to obtain 0.9553 is:

\[
= \text{NORM.S.DIST}(1.6989, \text{TRUE})
\]

The “TRUE” means the cumulative probability distribution. The result of 0.9553 shows that the 95% upper confidence limit for the probability of the daily workload exceeding 16 hours equals 4.47%, where 4.47% = 1 – 0.9553.

We make 2 comparisons with the 4.47% to highlight the usefulness of the result. One comparison is with the observed incidence of 2.27% (1/44) workdays, (Figure 1) and in the first row of Table 2. The observed incidence does not consider the sample size \( n \). The 95% upper confidence limit from the tables generated by Owen\(^{15} \) of 4.47% is 97% greater than the observed percentage of 2.27%. Had the sample size been 999,999, as below, then the 95% upper confidence limit would have been 0% greater than the observed value. However, under realistic sample sizes for operating room managerial decisions (Table 2),\(^{5,9,13-19} \) the observed incidences are of little value. A second comparison with insight would be to treat the sample mean \( \bar{X} \) as equaling the true population mean and the sample SD \( S \) as equaling the true population value. We would then use the inverse of the standard normal cumulative probability distribution:\(^{14} \)

\[
Z = (\bar{X} - \mu) / \sigma = (16 - 9.39053) / 3.05693 = 2.1621
\]

\[
1 - \text{NORM.S.DIST}(2.1621, \text{TRUE}) = 1.53\%
\]

The 95% upper confidence limit of 4.47% from tables generated by Owen\(^{15} \) is 192% greater than the asymptotic estimate of 1.53%. We recommend our consideration of proportional errors because those would be generalizable to other conditions and problems.

Our suggested alternative approach is to use a generalized pivotal quantity based on the properties of the normal distribution.\(^{16} \) First, we present our implementation,\(^{17} \) and then explain the terms. There was 95% assurance that at most 4.47% of workdays would have greater than 16 hours of anesthesiology time, the same as that obtained with tables generated by Owen.\(^{15} \) The Excel formula to calculate 4.47% is the following:

\[
= \text{SMALL}(1 - \text{NORM.S.DIST}(\sqrt{\text{CHISQ.INV(RANDARRAY(999999), 44-1)})} * (16 - 9.39053) / (3.05693 * \text{SQRT}(44-1)) + \text{NORM.S.INV(RANDARRAY(999999))} / \text{SQRT}(44), \text{TRUE}), 0.95 * (999999 + 1))
\]

Readers can copy and paste this formula into an Excel cell to obtain the answer of 4.47%. (Copy and paste can add line breaks, which will need to be deleted from the formula bar before selecting Enter.) Execution time was 4 seconds on a Dell XPS 13 9410 laptop computer. The fact that the same answer is obtained as the tables generated by Owen\(^{15} \) shows the suitability of the approach.

We consider each of the terms in the preceding formula in their sequence. For each of the 999,999 simulations, a \( \chi^2 \) distributed random number is calculated with \( n - 1 \) degrees of freedom. That is multiplied by the \( Z \) statistic, above, and then divided by the square root of \( n - 1 \). In addition, for each of the 999,999 simulations, a standard normal random variable is calculated and divided by the square root of \( n \). These 2 random variates and their multiplicands are summed. These 2 random variates are those encompassing the Student \( t \)-distribution. The inverse of the standard normal cumulative probability distribution is taken and then subtracted from 1. After this process has been repeated 999,998 more times, the results are sorted in ascending sequence and the 95th percentile is calculated. Each of the simulations is a prediction of future workload, conditional on the observed \( n, \bar{X} \), and \( S \). In other words, this method obtains 999,999 observations.

To use the Excel formula for other services or conditions, substitute a different sample size for the 44, critical threshold in hours for the 16, sample mean in hours for 9.39053, and sample SD in hours for 3.05693. Readers’ implementation for their practices would simply be to change those 4 numbers in the Excel formula. For example, as explained above, we used 14 hours as sensitivity analysis. Changing the “16” in the formula to “14” gives the revised upper 95% limit of 12.76%. (We recommend that readers try doing this.) To highlight the approach’s usefulness, suppose that the sample size was neglected, and the sample statistics treated as the population parameters. Then, using the formulas above, the matching \( Z \) = 1.5079 with matching probability of 6.58%:

\[
= 1 - \text{NORM.S.DIST}((14 - 9.39053) / 3.05693, \text{TRUE})
\]

Analyses of daily workload instead of anesthetics

The daily anesthetist’s workload was highly correlated with the time the last case finished each day.
In addition, the count of daily anesthetics was statistically independent among days (above). More anesthetics per day were associated with the anesthetist finishing later (Figure 3). That was inevitable and shows validity. The important result is a significantly lesser correlation between anesthetics per day and the anesthetist’s last case of the day’s ending time in hours (Figure 3) versus between the daily anesthesia workload and the ending time (Figure 2). The Pearson correlation between the end of the workday and the number of anesthetics equaled 0.64, while between the end of the workday and hours of cases equaled 0.85. The 0.64 was significantly less than the 0.85, P < .0001. Furthermore, when performing multivariable linear regression and controlling for the anesthetist’s daily workload (P < .0001), not only was there not a significant effect of cases per day (P = .066), but the estimated coefficient was negative, −0.76 extra hours finishing later per extra anesthetic that day. The implication is that the daily anesthetist’s workload of the veterinary dental service (Table 2, column 1) is the important measure, the endpoint for which we consider confidence limits on the probabilities of exceeding managerially relevant thresholds in hours.

Discussion

When calculating the allocated time (ie, the hours into which cases are scheduled; Table 1), an appropriate objective is to maximize the expected efficiency of use of the anesthetist’s and/or facility’s time (Tables 1 and 2). Often an appropriate secondary objective is to assure that the probability of working late does not exceed some maximum probability such as 20% (ie, 1 day in 5) or 10% (ie, 1 day every other week). In the current study, we took advantage of the features of a veterinary dental clinic to confirm the accuracy and usefulness of a generalized CI, implementable in Excel. We also confirmed that the workload provides the information on how late the anesthetist and team would work, not the caseload, even under the unusual and therefore scientifically sound condition that caseload had the greatest opportunity to be informative.

Principles of scheduling cases into allocated time envisioned using a single table

Scheduling cases into allocated time is understood in detail. We use the veterinary dental clinic data as teaching examples, simplified as if in 1 operating room. The analyses being summarized...
were performed by surgical service (Table 1), as shown in the Results.

There were n = 115 anesthesia durations, sample mean 3.59290 hours. (As a reminder, from the first paragraph of the Methods, these durations are from premedication to tracheal extubation.) The logarithms of the durations followed a normal distribution, based on the Shapiro-Wilk test (P = .56) and normal distribution plot (Figure 4).25,26 The mean and SD of the log10 durations in hours were 0.53192 and 0.14564, respectively. The mean time for 2 cases equals 7.2 hours:

\[
\text{AVERAGE}(10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564), \text{IF}(X>12,1,0))
\]

The result of 7.2 hours equals the sum of the means 2 x 3.59290, because the mean of sums equal the sum of means. There is a small 1.3% frequency of working very late, longer than 12 hours:

\[
\text{AVERAGE}(\text{LET}(X,10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564), \text{IF}(X<3.59290,3.59290,X))) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564))
\]

(As another reminder to readers, when copying and pasting into the Excel formula bar, before pressing Enter, nonprintable characters like line breaks need to be deleted.) If 3 cases were performed, the mean would equal 10.8 hours (ie, 3 x 3.59290), and the probability of working longer than 12 hours would be 26.3%:

\[
\text{AVERAGE}(\text{LET}(X,10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564), \text{IF}(X<3.59290,3.59290,X))) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564))
\]

The mean also would be longer if there were 2 cases, but with the second case not starting early if the first finishes early, 7.68 hours:

\[
\text{AVERAGE}(\text{LET}(X,10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564), \text{IF}(X<3.59290,3.59290,X))) + 10^\text{NORM.INV}(\text{RANDARRAY}(999999,1),0.53192,0.14564))
\]

We use these calculated results in sequence in the rest of this discussion section.

Because allocated time was calculated using actual workloads (Table 2), that decision considered inaccuracy in case duration prediction and the risks of case cancellation.24 Cases should be scheduled into the allocated time using the unbiased estimate of the contribution of each case to the workload.26,29 That is, by definition, the expected value (eg, the sample mean duration, 3.59290 hours).26,29

Although the mean time for 2 cases was 7.2 hours, the allocated time of 7 hours had a smaller mean inefficiency of use of anesthesia time than 8 hours (Table 2). This example highlights that staff should be scheduled for hours modestly longer than the allocated time to prevent working late.1 The allocated time literally refers to the hours into which cases are scheduled, not the staff.24 For example, at the clinic, the staff may be scheduled for 8 hours.

The optimal allocated time was 7 hours, among chosen options (Table 2), but the mean time for 2 cases equaled 7.2 hours. These results are consistent because the calculation of the allocated time (Table 2) depends on the unchanged workload.25,26 Thus, cases should be scheduled to minimize expected overutilized time.1,7 2 cases per procedure table daily. Cases being scheduled slightly into overutilized time shows why it is so useful to have a way to calculate the probability of long work hours,13 the results of the current article.

Figure 4—Normal quantile plot of the anesthesia durations and times from premedication through extubation. If a normal distribution, then the data would follow a straight line, as shown to hold. The corresponding Shapiro-Wilk test P = .56. As context, log10(duration) of 1.8 is 63 minutes (ie, approx 1 hour) and 2.8 is 630 minutes (ie, approx 10 hours).
Generally, for services with few (eg, 2 or 3) cases per table or operating room per day, there is small potential to no potential for machine learning that would perfectly predict anesthesia duration to increase efficiency. If magic happened, every case duration estimated perfectly, the allocated time selected months ahead would equal the mean time for the sum of cases, because there would never be over-utilized time. Allocated time would equal either 7.2 hours if 2 cases per table per day or 10.8 hours if 3 cases per day. Such a perfect prediction of anesthesia duration would neither change the mean nor the SD, just that the total time would be known when the last case of the day is scheduled. The frequency of working longer than 12 hours would still be 1.3% or 26.3%, for 2 or 3 cases, respectively. The latter risk of working very late is too high for the clinic and most healthcare organizations. Thus, there would be no value in more accurate duration estimation, because 2 cases are still scheduled. This conclusion is robust for veterinary care as sedation or general anesthesia are needed to perform a complete examination and imaging to achieve those more accurate duration estimates.

The clinic has all patients arrive at the start of the workday. The mean time of 7.20 hours to complete 2 cases was based on the second case starting right after the first case finishes. At the dental clinic, this was done by having 3 physical tables for 2 cases. Because anesthesia times generally follow log-normal distributions, and the mean exceeds the median for log-normal distributions, most (56.4%) of cases that are not the first cases of the day can start early. Suppose, instead, cases do not start early, like trains and buses. Then, the mean time for the 2 cases would be significantly longer, 7.68 hours. Veterinary anesthetists have the advantage over human anesthetists in that the patients cannot tell time and judge waiting. 35 34

Limitations

Our study examined 1 Canadian veterinary clinic as a model system to answer a problem recognized as important for 25 years. Nevertheless, several earlier results suggest the generalizability of the conclusions. First, the daily anesthesia workloads of services routinely follow normal distributions. Furthermore, even when not normally distributed, the calculated allocated times among fixed weekday durations are usually the same as would be calculated based on normal distribution. If right skewed, calculations can be repeated using comparable generalized CIs for the log-normal distribution (equations 1 to 3 of Dexter and Ledolter). Second, the sample size of \( n = 44 \) was typical for allocating time based on minimizing the inefficiency of the use of anesthetists’ time. 6 19 In practice, services’ workloads vary on weekdays because different surgeons are operating. 6 19 When allocating anesthesia time, and controlling for day of the week, labor costs are the least when using 6 months to 1 year of data, the best observed being approximately 44 workdays. 6 19 Third, the coefficient of variation of the daily workload, 32.6%, is typical among human anesthetists’ operating rooms. A hospital audit showed most service and weekday combinations (43/52) with coefficients of variation > 30%. Individual human surgeons have even greater proportional variability, 70/74, with coefficients of variation > 30% on days with at least 1 scheduled case. Some days have a very low anesthetist workload, and some days have a very large workload. The substantial variability of workload is precisely why applying statistical methods has value, either to reduce the variability by adjusting case scheduling or by providing realistic predictive information to the anesthetist and other clinic staff.

Our results showed the validity and accuracy of a generalized pivotal quantity to calculate upper CIs for percentages of workloads exceeding a threshold. Although that is what was studied using the veterinary clinic data, we expect multiple other veterinary applications. These are illustrated with 4 examples. First, in the situation of a veterinary anesthesiologist providing consulting services, the anesthesiologist goes to a clinic with information known ahead of the total hours scheduled by the clinic. There are historical data for the site on daily differences in hours between actual and scheduled hours for the day. These differences routinely follow normal distributions (Figure 1). Therefore, our results show how to calculate an upper confidence limit on the probability that the anesthetist’s time on site exceeds a threshold number of hours longer than that scheduled. Second, anesthesia times of cases regularly follow log-normal distributions (Figure 4). A generalized pivotal quantity using logarithms can be used for the upper confidence limit of the probability that an add-on case will fit into allocated but otherwise underutilized time. Third, readiness for patient discharge could be predicted to follow the human anesthesia equivalent of a postanesthesia care unit stay, which follows log-normal distributions. Our results show that generalized pivotal quantities can be used for the upper confidence limit of the probability that a patient will not be ready for discharge for a period longer than a threshold (eg, greater than 3 hours). Fourth, suppose that 1 anesthetist is giving another a break during the surgical period (eg, for lactation session) after the incision but before the end of surgery. Surgical times follow log-normal distributions. Our results show how to calculate the lower confidence limit on the probability that at least 30 minutes is available. These 4 examples show the multiple opportunities to apply statistical methods to quantify risks of exceeding thresholds of workload, for veterinary, like human, operating room management.

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References
1. Dexter F, Wachtel RE, Epstein RH. Decreasing the hours that anesthesiologist and nurse anesthetists work late by making decisions to reduce the hours of over-utilized operating room time. Anesth Analg. 2016;122(3):831-842. doi:10.1213/ANE.00000000000001136
10. Dexter F, Macario A, Qian F, Traub RD. 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(5):1501–1508. doi:10.1097/00000542-199911000-00044
19. Epstein RH, Dexter F. Statistical power analysis to estimate how many months of data are required to identify operating room staffing solutions to reduce labor costs and increase productivity. Anesth Analg. 2002;94(5):640–643. doi:10.1097/00000539-200205000-00029
31. Wang Z, Dexter F. More accurate, unbiased predictions of operating room time increase labor productivity with the same staff scheduling provided allocated hours are increased. Periop Care Oper Room Manag. 2022;29:100286. doi:10.1016/j.pcor.2022.100286


35. Epstein RH, Dexter F. Rescheduling of previously cancelled surgical cases does not increase variability in operating room workload when cases are scheduled based on maximizing efficiency of use of operating room time. *Anesth Analg.* 2013;117(4):995–1002. doi:10.1213/ANE.0b013e3182a0d9f6


39. Dexter F, Ledolter J. Bayesian prediction bounds and comparisons of operating room times even for procedures with few or no historic data. *Anesthesiology.* 2005;103(6):1259-1267. doi:10.1097/00000542-200512000-00023


42. Titler S, Dexter F, Epstein RH. Percentages of cases in operating rooms of sufficient duration to accommodate a 30-minute breast milk pumping session by anesthesia residents or nurse anesthetists. *Cureus.* 2021;13(6):e12519. doi:10.7759/cureus.12519

**Supplementary Materials**

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