

Numbers of Simultaneous Turnovers Calculated from Anesthesia or Operating Room Information Management System Data

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BACKGROUND: More personnel are needed to turn over operating rooms (ORs) promptly when there are more simultaneous turnovers. Anesthesia and/or OR information management system data can be analyzed statistically to quantify simultaneous turnovers to evaluate whether to add an additional turnover team.

METHODS: Data collected for each case at a six OR facility were room, date of surgery, time of patient entry into the OR, and time of patient exit from the OR. The number of simultaneous turnovers was calculated for each 1 min of 122 4-wk periods. Our end point was the reduction in the daily minutes of simultaneous turnovers exceeding the number of teams caused by the addition of a team.

RESULTS: Increasing from two turnover teams to three teams reduced the mean daily minutes of simultaneous turnovers exceeding the numbers of teams by 19 min. The ratio of 19 min to 8 h valued the time of extra personnel as 4.0% of the time of OR staff, surgeons, and anesthesia providers. Validity was suggested by other methods of analyses also suggesting staffing for three simultaneous turnovers. Discrete-event simulation showed that the reduction in daily minutes of turnover times from the addition of a team would likely match or exceed the reduction in the daily minutes of simultaneous turnovers exceeding the numbers of teams. Confidence intervals for daily minutes of turnover times achieved by increasing from two to three teams were calculated using successive 4-wk periods. The distribution was sufficiently close to normal that accurate confidence intervals could be calculated using Student's *t* distribution (Lilliefors' test $P = 0.58$). Analysis generally should use 13 4-wk periods as increasing the number of periods from 6 to 13 significantly reduced the coefficient of variation of the averages but not increasing the number of periods from 6 to 9 or from 9 to 13.

CONCLUSION: The number of simultaneous turnovers can be calculated for each 1 min over 1 yr. The reduction in the daily minutes of simultaneous turnovers exceeding the number of teams achieved by the addition of a turnover team can be averaged over the year's 13 4-wk periods to provide insight as to the value (or not) of adding an additional team.

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Neither anesthesiologists nor surgeons desire prolonged operating room (OR) turnover times.^{1,2} One effective way to reduce turnover times is to use additional personnel (e.g., extra anesthesia technicians and/or postanesthesia care unit nurses).³⁻⁵ In the United States, such personnel must usually be paid for by the facility due to regulatory issues.⁶ Anesthesiologists have an incentive to persuade administrators to increase the OR nursing budget to include more turnover personnel,

as reducing excessive idle time can increase anesthesia group productivity.⁷ Because quantitative analysis enhances the persuasiveness of arguments,⁸ we studied how OR and/or anesthesia information management system data can be analyzed statistically to quantify simultaneous turnovers to evaluate whether to add an additional turnover team (e.g., housekeeper and anesthesia technician). We studied simultaneous turnovers being as the number of personnel needed to turn over

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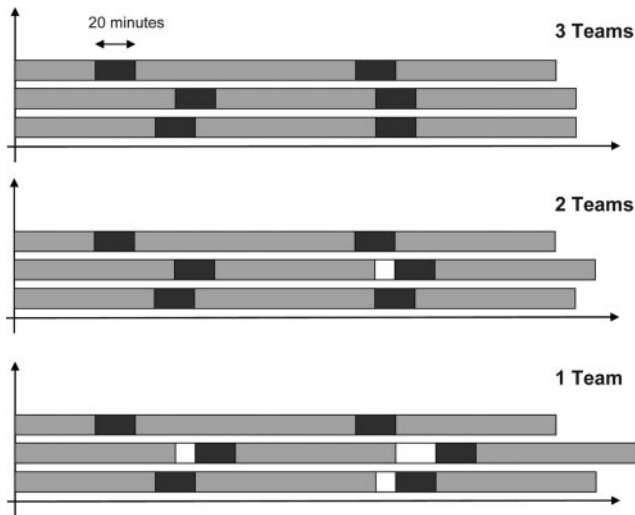


Figure 1. Gantt charts showing that the effect of adding a turnover team on daily minutes of surgeon experienced turnover times can be predicted by minutes of simultaneous turnovers exceeding the number of teams. In the schematic, time is plotted along the horizontal axis. Each row represents an operating room (OR). The panes show turnover times for three turnover teams, two teams, and one team. The long light gray bars represent times that patients are in ORs. The dark gray bars are the cleanup and setup times. The white bars represent delays contributing to turnover times (i.e., nothing is happening in the OR because the turnover team is elsewhere). With three teams, the minutes of simultaneous turnovers exceeding the threshold of three teams = 0 min. With two teams, the minutes of simultaneous turnovers exceeding the threshold of two teams = 10 min. Thus, an increase from two teams to three teams results in a 10 min reduction in the daily minutes for which the number of simultaneous turnovers exceeds the numbers of teams, where 10 min = 10 – 0 min. In comparison, an increase from two turnover teams to three teams reduces the total surgeon experienced turnover time by 10 min. The two end points match. With one team, the minutes of simultaneous turnovers exceeding the threshold of one team = 40 min. An increase from one team to two teams results in a 30 min reduction in the daily minutes of simultaneous turnovers exceeding the numbers of teams, where 30 min = 40 – 10 min. In comparison, an increase from one turnover team to two teams reduces the total minutes of surgeon experienced turnover time by 30 min. For this example, the two end points match.

ORs promptly is positively correlated with the number of simultaneous turnovers (Figs. 1 and 2). We developed the statistical method using 9 yr of data from an outpatient facility with six staffed ORs, validated the method, and then applied the method to a large tertiary suite with several months of data.

METHODS

There were 53,716 cases performed at the outpatient facility during its 2345 workdays from December 20, 1998, to April 26, 2008. All procedures were elective. No cases were performed on holidays or weekends. Data used for each case were, room, date of surgery, time of patient entry into the OR, and time of patient exit from the OR, entered into an Excel spreadsheet (Microsoft, Redmond, WA). Using Visual Basic

for Applications, turnover times were calculated for each case and set equal to 90 min when longer than 90 min.^{9,10} The resulting 37,282 turnovers totaled 799,787 min. Turnovers were considered to be simultaneous if they overlapped in time by at least 1 min. The number of simultaneous turnovers was calculated for each 1 min over the 122 studied 4-wk periods. In routine practice, we use 13 4-wk periods (see Results).

An array stored in 1 min increments was created that stored the number of simultaneous turnovers, as described previously for studies of staffing in postanesthesia care units.¹¹ The daily minutes with the number of simultaneous turnovers exceeding a threshold number of teams was calculated. By this we mean, precisely, the daily minutes of simultaneous turnovers during which there were more ORs to be turned over than there were turnover teams available. For example, if the threshold were three teams, and if for 1 min there were five simultaneous turnovers, then that minute contributed 2 min to the measured value, because there were two ORs without assistance for that 1 min interval. Depending on a facility's organization, a turnover team may not be needed for the entire turnover. Results are proportional if a turnover team is needed for only a fraction of the turnover time.

Two-sided 95% confidence intervals (CIs) were calculated for the reduction in the daily minutes for which the number of simultaneous turnovers exceeded a specified number of teams, with reductions calculated for additions of one turnover team. This approach of studying incremental differences was described previously for studying anesthesia staffing in afternoons.^{12,13} The averages of 4-wk periods of daily differences were treated as following a normal distribution such that CI were calculated using Student's *t*-distribution. Lilliefors' test was used to confirm this assumption.¹⁴

As a potential alternative end point, we calculated the percentage of turnover time attributable to turnovers occurring when the number of simultaneous turnovers exceeded the number of teams. To calculate these percentages, we used larger bin sizes of 8-wk periods to have no bins with zero in the numerator. The sum over each 8-wk period of the minutes of simultaneous turnovers exceeding the number of turnover times was divided by the total minutes of turnover time during the period. Two-sided 95% CI were calculated by taking the Freeman-Tukey transformation of the counts from each 8-wk period, applying the Student's *t*-distribution to the transformed values, and then taking the inverse.^{15,16} The percentages were pooled because personnel responsible for turnovers generally work 8 h shifts, 5 days a week, corresponding to when most turnovers occur.¹⁰ The percentages were pooled also because successive turnover times were correlated.¹⁰

As another potential alternative end point, the daily peak number of simultaneous turnovers was calculated by using bin sizes of 1 day. The Clopper-Pearson

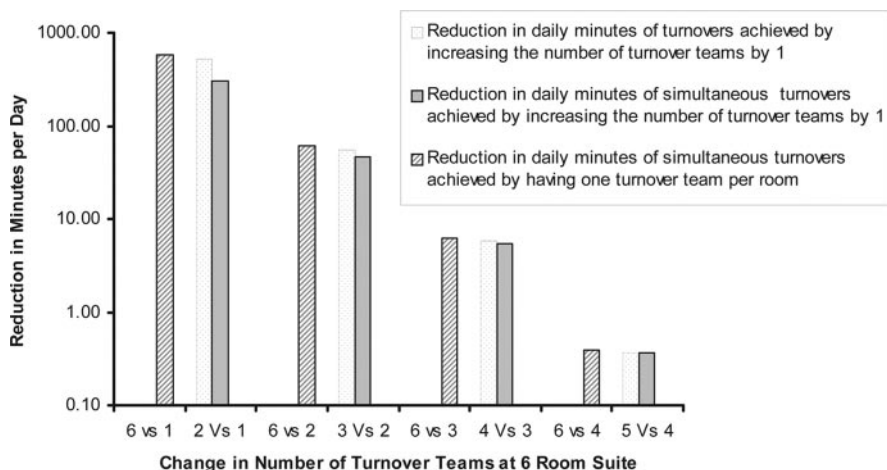


Figure 2. Simulated reductions in daily minutes of surgeon experienced turnover times from the addition of a turnover team match or exceed the reduction in daily minutes of simultaneous turnovers exceeding threshold of the number of teams. The methodology is described in the last two paragraphs of the Methods. The figure is presented in the same format as Figure 3 for comparison, with dark boxes in both representing our recommended study end point. The comparisons between adjacent bars are analogous to the comparisons made in Figure 1. The light boxes in this figure show the extra time experienced by the physicians, called “makespan” in the operations research/industrial engineering fields. Unlike Figures 3–5, there is no box around three turnover teams, because with simulation, any number of turnover teams can be studied. The figure shows that the reduction in total turnover time of the suite (e.g., as experienced by surgeons) from the addition of one team will be at least the reduction in minutes of simultaneous turnovers achieved by an increase in the threshold number of teams by one team. As explained in the second to last paragraph of the Results, the reduction in total turnover time will be no more than that achieved by increasing the number of teams to one team per operating room. Consequently, as the numbers of teams is increased, the absolute accuracy of the method of Figure 3 is improved.

method was used to calculate one-sided 95% CI for the cumulative distribution of the percentage of days with the peak number of simultaneous turnovers exceeding a threshold number of simultaneous turnovers.^{17,18}

We will show, below, that our recommended method of analysis is two-sided 95% CI for the reduction in the daily minutes for which the number of simultaneous turnovers exceeds the number of turnover teams, as achieved by the addition of one extra team. We considered the appropriate number of 4-wk periods for use in routine monitoring. Deciding to increase staffing, hiring the additional personnel, and training can typically take around half a year. Budgeting usually is reevaluated annually. Thus, 6 and 13 4-wk periods (i.e., 24 and 52 wk, respectively) serve as the minimum and maximum intervals. We calculated the coefficient of variation (CV) of the moving average over the $n = 122$ 4-wk periods using 6 periods ($n = 117$), using 9 periods ($n = 114$), and using 13 periods ($n = 110$). Comparison of coefficients of variation between different numbers of 4-wk periods was performed asymptotically using two-group analyses.¹⁹

Finally, discrete event simulation was used to study the influence of the numbers of turnover teams on both our recommended end point and the reduction in the total daily minutes of turnovers at the suite, matching the comparison showed in Figure 1. The 53,716 cases studied were performed in 14,070 combinations of six ORs and 2345 workdays. The mean \pm standard deviations of OR times = 1.41 ± 0.95 h and of turnover times = 0.32 ± 0.28 h. ARENA (v8.0, Rockwell Software, Sewickley, PA) was used to simulate 14,070 identical OR workdays. For each OR on

each workday, an OR time was simulated using a log-normal distribution with the observed mean and standard deviation.²⁰ If <9 h, a turnover time and another OR time were simulated. If the sum of the three was <9 h, then all three are performed. Another turnover time and OR time were simulated. If adding those two to the preceding three exceeded 9 h, then only the first three were used. If the sum of the five events did not exceed 9 h, then all five events were included. The process was continued until 9 h was exceeded. The resulting duration of the simulated workday was 7.71 ± 0.53 h.

The simulation model was used for testing the five scenarios in which the maximum number of turnover teams working in the surgical suite was specified. For the first scenario, six turnover teams were assumed always to be available, equal to the number of ORs. Thus, no OR ever waited for cleanup or setup, and these times were considered to be the turnover time. Simulations were repeated with five teams reduced stepwise to one team. With fewer teams, ORs sometimes waited for cleaning to start, and the turnover time was increased, as shown in Figure 1. For example, without an anesthesia technician, cleaning and setup of anesthesia equipment may wait until the anesthesia provider returns from the postanesthesia care unit. The result was that the OR finished later in the workday, increasing the work hours of the surgeons, anesthesia providers, and OR nurses. This increase in “makespan” (a term used in the field of operations research/industrial engineering), measured in minutes, quantified the increased waiting experienced by surgeons. The number of simulated OR-day combinations

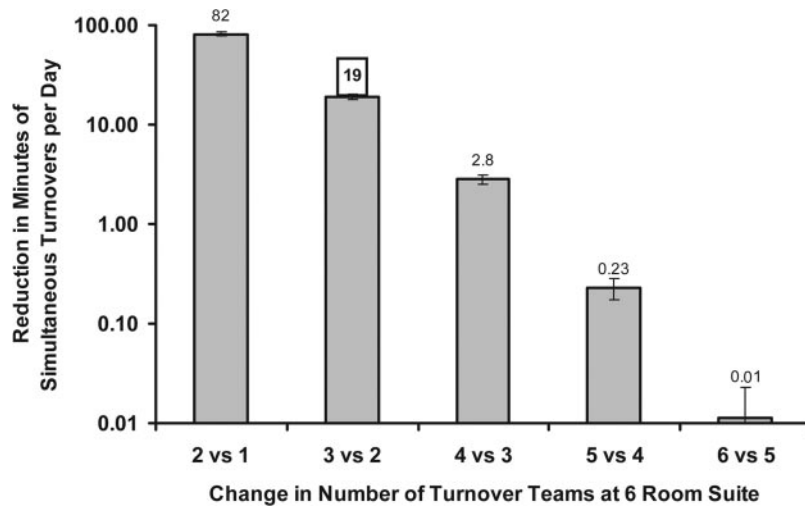


Figure 3. Average reduction in minutes of simultaneous turnovers per day exceeding the threshold number of turnover teams. For example, (A) calculate the total minutes of simultaneous turnovers exceeding the threshold of two turnover teams. A 5-min period with four simultaneous turnovers would contribute 10 min, where 10 min = (5 min) × (4 simultaneous turnovers – 2 teams). (B) Repeat using three turnover teams. The value of 19 min in the figure equals the average of A–B. The error bars are 95% confidence intervals. The figure shows that each increase in the threshold by one team is associated with large decreases in the incremental reduction in turnover time resulting from a further 1 increase in the number of teams. However, the data were measured with 2–3 teams, analogous to the situation described in Figures 1 and 2. This is indicated by the value of 19 min labeled with a bold box. The facility had 2–3 anesthesia technicians during the study period.

was sufficient for widths of 95% CIs for all reported end points to be <0.6% of the value of the end point. Being so narrow, these CIs are not displayed.

RESULTS

Figure 3 shows the average reduction in minutes of turnovers per day from each unit increase in the number of teams. Increasing from 1 to 2 teams reduced the daily minutes for which the number of simultaneous turnovers exceeded the numbers of teams by 82 min/day. Increasing from 2 to 3 teams reduced the daily minutes by 19 min. Increasing from 3 to 4 teams reduced the daily minutes by 2.8 min/day.

Figure 4 provides further insight into the large changes resulting from each incremental increase in the numbers of teams in Figure 3. The number of simultaneous turnovers exceeded two teams for 6.2% of turnover times. In contrast, one team was exceeded for much (30%) of the turnover time, whereas three teams were exceeded for little (0.8%) of the turnover time.

Figure 5 shows that if 6.2% were acceptable, the consequence would be that on most days (81%) there would be at least one event when the number of simultaneous turnovers exceeds the number of teams. If a manager wanted to reduce this rate of exceedance to below 1 event/week (20% of days) or even 1 event/3 weeks (6.7%), four teams would be required.

We examined further how to analyze statistically the incremental reduction in minutes for which the number of simultaneous turnovers exceeds the number of teams by the addition of another team.

First, Figure 6 shows a histogram of the $n = 122$ averages over 4-wk periods of the reduction in the

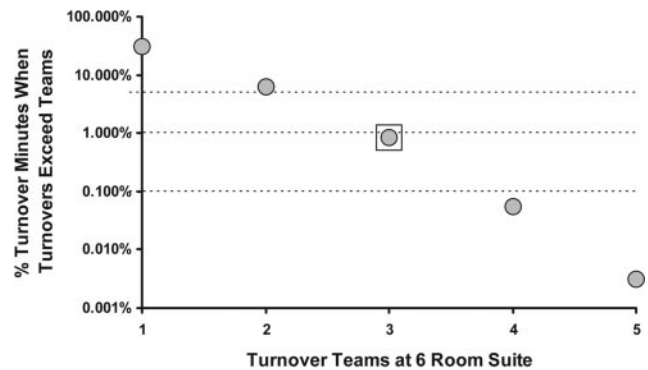


Figure 4. Percentages of overall minutes of turnover times attributable to minutes of turnovers occurring when the number of simultaneous turnovers exceeded the threshold number of teams on the horizontal axis. For example, when the number of simultaneous turnovers exceeded two teams, there was a total of 6.2% of all turnover time. The datum for three turnover teams is listed with a square because the facility had 2–3 anesthesia teams and results of the analyses (e.g., Fig. 3) suggest that three turnover teams is appropriate. Two-sided 95% confidence intervals are present but are sufficiently narrow to be obscured by the circles.

daily minutes of turnover times achieved by increasing the threshold of exceeded turnovers from 2 to 3 teams. The distribution was sufficiently close to normal for Student's t -distribution to give accurate CIs (Lilliefors' test $P = 0.58$).

Second, the number of 4-wk periods for use in routine monitoring was considered. The CV of the moving average using six 4-wk periods was 27%, using 9 periods was 25%, and using 13 periods was 22%. The improvement in the CV was significant between 6 and 13 periods ($P = 0.039$, $Z = 2.06$) but not between 6 and 9 periods ($P = 0.36$, $Z = 0.92$) or between 9 and 13 periods ($P =$

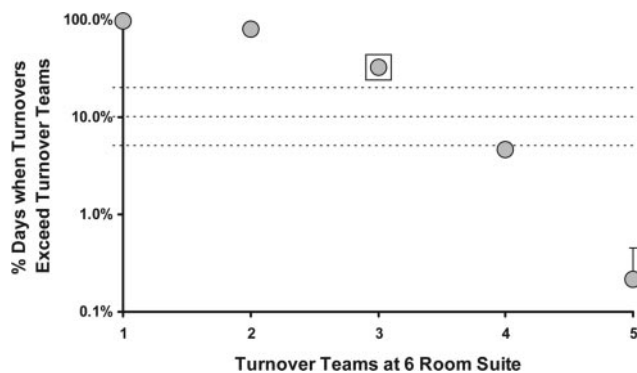


Figure 5. Percentage of workdays with at least 1 min for which the number of simultaneous turnovers exceeded the listed number of teams. The datum for three turnover teams is listed with a square because the facility had two to three anesthesia teams, and results of the analyses (e.g., Fig. 3) suggest that three turnover teams is appropriate. One-sided 95% upper confidence bounds are given for the cumulative distribution of the percentage of days with the peak number of simultaneous turnovers exceeding the number of turnover teams.

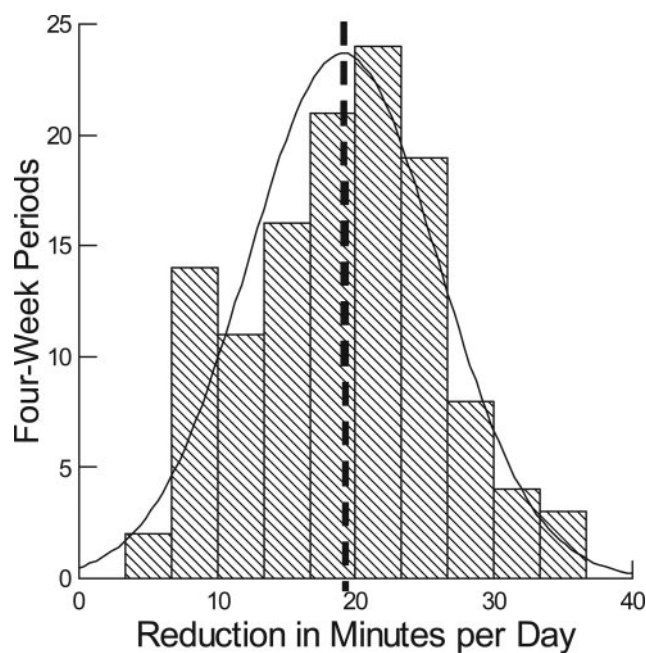


Figure 6. Histogram of the averages over 4-wk periods of daily differences of turnover times achieved by increasing the number of turnover teams from 2 to 3. The difference corresponds to the middle bar labeled 19 min in Figure 3. The dotted vertical line shows 19 min. The best fit normal probability density curve is overlaid ($P = 0.58$, $n = 122$ 4-wk periods).

0.25, $Z = 1.15$). Therefore, we recommend the use of 1 yr of data.

Third, discrete-event simulation was performed using the raw data's parameter values. Figure 2 shows that the reduction in daily minutes of turnover times from the addition of a turnover team matches or exceeds the daily minutes for which the number of simultaneous turnovers exceeds the number of teams. In the example in Figure 1, the two match. The maximum potential reduction in total turnover time equals the reduction in daily minutes of simultaneous turnovers achieved by increasing the number of teams

Table 1. Application of Method to 24 Operating Room Tertiary Surgical Suite

| | 3 vs 4 | 4 vs 5 | 5 vs 6 |
|--|--------|--------|--------|
| Reduction in minutes per day of simultaneous turnovers exceeding number of turnover teams | | | |
| Mean | 66 | 27 | 9 |
| Lower 95% CI | 61 | 23 | 7 |
| Upper 95% CI | 71 | 31 | 12 |
| Maximum potential reduction in minutes of turnover time per day by increasing number of turnover teams | | | |
| Mean | 102 | 36 | 9 |

The "Lower 95% CI" and "Upper 95% CI" values refer, respectively, to lower and upper 95% confidence bounds for the mean calculated using 13 4-wk periods of data. The maximum potential reduction in minutes of turnover times achieved by a unit increase in the number of teams was calculated by summing the successive decreases in the mean reduction to the right of the baseline turnover team level. For example, an increase in the number of teams from 3 to 4 can directly reduce total turnover time by at most 102 min, where $102 \text{ min} = 66 + 27 + 9$. An increase in the number of teams from 4 to 5 can directly reduce total turnover time by at most 36 min, where $36 \text{ min} = 27 + 9$.

CI = confidence interval.

to the number of ORs. We describe the relevance by referring to Figure 3.

First, when the number of teams is relatively low, the reduction in the minutes for which the number of simultaneous turnovers exceeds the number of turnover teams as achieved by increasing the number of teams by 1 underestimates the reduction in the total daily minutes of turnover time. However, the underestimation is not sufficiently large to alter the managerial decision as to whether to add a team. When the number of turnover teams is relatively high, compared with the numbers of ORs, the reduction in minutes during which the number of simultaneous turnovers exceeds the numbers of teams achieved by increasing by one team is an accurate estimate.

Second, the maximum potential reduction in total turnover time of the suite can be calculated from the observed data without simulation because there is an upper and lower limit to the potential benefit of increasing the number of teams. For example, suppose the anesthesia group were sharing analysis results with hospital administration showing the potential value in hiring another anesthesia technician and housekeeper to increase from 2 turnover teams to 3 teams. There was a 19 min reduction in the minutes for which the number of simultaneous turnovers exceeded the number of teams (Figure 3). The corresponding increases from three turnover teams to four teams was 2.8 min, from four turnover teams to five teams was 0.23 min, and from five turnover teams to six teams was 0.01 min (Fig. 3). Further increases in the number of teams would result in savings of 0 min, because there are six ORs. Summing these values (using the raw data to avoid rounding) gives 24 min. The corresponding saving of extra minutes of turnover time from the addition of one team is at least the observed 19 min but no more than 24 min.

Table 1 gives an example of application of the statistical method to a larger suite using 1 yr of data, as displayed for regular use. We expect a 27 min reduction per day in times when the number of simultaneous turnovers exceeds the number of turnover

teams by an increase from four to five teams. The maximum potential direct reduction in turnover time experienced by the surgeons, anesthesia providers, and nurses would be 36 min.

DISCUSSION

The methodology we propose to decide whether to add one turnover team is straightforward and can easily be implemented using the steps listed in the first three paragraphs of the Methods. Any vendor's spreadsheet supporting addition of programming code can be used for this purpose.

Figure 3's mean 19 min reduction in minutes of simultaneous turnovers by adding one turnover team should be balanced against increases in working times of staff who participate in the team. An 8 h day has 480 min. The ratio of 19 to 480 min values the time of extra personnel as 4.0% of the time of OR staff, surgeons, and anesthesia providers, since $4.0\% = 19 \text{ min}/480 \text{ min}$. In other words, the facility would be paying for 480 min of work by the extra turnover team member to save 19 min of idle OR time. The value of 4.0% can be compared with thresholds for ORs and physicians waiting for patients. Applying national compensation data, the value of patients' time averages 5.3% that of OR and physicians.²¹ At a tertiary suite, patients entered the holding area after the OR was ready 5.0% of the time.²² Exceeding 3 teams at a 4.0% rate is close to these referenced values of 5.3% and 5.0%.

Our methodology does not differentiate among times of the day. Most turnovers occur in the middle of the workday (e.g., 10:00 AM to 2:00 PM) not at the end. If part-time people were to be hired to improve turnover times, their work hours can best be determined by calculating which hours of the day have the largest numbers of prolonged turnovers. The methodology is described in Ref. 10 and reviewed in Ref. 23.

An alternative approach to our analysis of Figure 3 would be to use the discrete-event simulation of Figure 2 under routine circumstances to evaluate the impact of adding turnover teams.²⁴ However, developing such models tends to be expensive and needs special software and expertise. Detailed data on workflow and processes would be needed to evaluate the impact of adding individual members of a team (e.g., one anesthesia technician). Thus, we recommend discrete-event simulation for research as used in the current article but not for routine use.^{10,11,16,24}

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