An Observational Study of Surgeons' Sequencing of Cases and Its Impact on Postanesthesia Care Unit and Holding Area Staffing Requirements at Hospitals

Eric Marcon, PhD*

Franklin Dexter, MD, PhD†‡

BACKGROUND: Staffing requirements in the operating room (OR) holding area and in the Phase I postanesthesia care unit (PACU) are influenced by the sequencing of each surgeon's list of cases in the same OR on the same day.

METHODS: Case sequencing was studied using 201 consecutive workdays of data from a 10 OR hospital surgical suite.

RESULTS: The surgeons differed significantly among themselves in their sequencing of cases and were also internally nonsystematic, based on case durations. The functional effect of this uncoordinated sequencing was for the surgical suite to behave overall as if there was random sequencing. The resulting PACU staffing requirements were the same as those of the best sequencing method identified in prior simulation studies. Although sequencing "Longest Cases First" performs poorly when all ORs have close to 8 h of cases, at the studied hospital it performed no worse than the other methods. The reason was that some ORs were much busier than others on the same day. The standard deviation among ORs in the hours of cases, including turnovers, was 3.2 h; large relative to the mean workload. Data from 33 other hospitals confirmed that this situation is commonplace. Additional studies showed that case sequencing also had minimal effects on the peak number of patients in the holding area.

CONCLUSIONS: The uncoordinated decision-making of multiple surgeons working in different ORs can result in a sufficiently uniform rate of admission of patients into the PACU and holding that the independent sequencing of each surgeon's list of cases would not reduce the incidence of delays in admission or staffing requirements.

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Hospital, professional, and societal costs are increased by unnecessary postanesthesia care unit (PACU) and operating room (OR) holding area staffing costs and by delays in admission into the PACU and holding area. The sequencing of each surgeon's list of cases in the same OR on the same day influences staffing requirements in the Phase I PACU and OR holding area (Table 1) (1). For small facilities with just a few ORs, the benefits of case sequencing are both seemingly obvious (Table 2) and impressive in practice (1,2). For large PACUs and holding areas, whether case sequencing achieves benefits is unclear (1), particularly compared to the good performance of adjusting staffing and beds to match workload using statistical optimization (1,3–6).

Recently, we performed computer simulation studies to evaluate the relative performance of different methods for the independent sequencing of each surgeon's list of cases to reduce PACU staffing and/or the delays in PACU admission (7). Table 1 lists the methods. The sequencing method that performed the best at reducing PACU staffing requirements and delays in PACU admission was MIX sequencing: shortest duration case, longest case, second shortest, second longest, and so forth. Random sequencing performed almost as well. The current article uses observational data to test two hypotheses drawn from these results:

Hypothesis 1 [Observational] : Surgeons' case sequencing at the study hospital was effectively heterogeneous with respect to case durations not just among surgeons, but for each surgeon.

Hypothesis 2 [Random] : The uncoordinated case sequencing decisions of multiple surgeons resulted in PACU staffing requirements at the study hospital that

From the *Department of Manufacturing System Management and Maintenance, Jean Monnet University, Saint Etienne, France; Departments of †Anesthesia, and ‡Health Management and Policy, University of Iowa, Iowa City, Iowa.

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Address correspondence and reprint requests to Franklin Dexter, Anesthesia 6-JCP, University of Iowa, Iowa City, IA 52242. Address e-mail to franklin dexter@uiowa.edu.

FD is Director of the University of Iowa's Department of Anesthesia's Division of Management Consulting. He receives no funds personally other than his salary from the State of Iowa, including no travel expenses of honorarium, and has tenure with no incentive program.

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Table 1. List of Methods Used to Sequence a Surgeon's List of *n* Cases in the Same Operating Room on the Same Day

Abbreviation	Description using L(1) shortest, L(2) second shortest, . . ., L(*n*) longest
Single	Single case
LCF	Longest case first L(n), L(n − 1), . . ., L(2), L(1)
SCF	Shortest case first L(1), L(2), . . ., L(n − 1), L(n)
MIX	MIXture of case durations L(1), L(n), L(2), L(n − 1), L(3), L(n − 2), . . .
Other	Other sequence Sequence of three or more cases other than LCF, SCF, or MIX Three of these other sequencing methods were considered in Ref. 7

LCF = longest cases first; SCF = shortest cases first; mix = mixture of case deviations.

were the same as that which would be produced by random sequencing.

For Hypothesis 1, we refer to the sequencing as "effectively heterogeneous," since a surgeon may be systematically sequencing cases, but have many constraints due to patient conditions.

The effective difference in the simulations between MIX and random sequencing was simply that random sequencing sometimes produced unusual, random events with many patients arriving simultaneously. However, in the real world, managers make decisions on the day of surgery to mitigate the effects of disadvantageous random sequences (7). Furthermore, MIX sequencing is the same as Shortest Cases First (SCF) sequencing when a surgeon has only 1 or 2 cases.

Hypothesis 3 [MIX] : The observed sequence of cases at the study hospital would achieve the same PACU staffing requirements at the hospital as does MIX and random
sequencing.

In our simulations, sequencing cases by Longest Cases First (LCF) produced the largest PACU staffing requirements and greatest frequency of delays in PACU admission (7). Although LCF can permit brief OR cases to be moved from one OR to another at the end of the workday thereby reducing over-utilized OR time, the benefit for the surgical suite was found to be negligible, overwhelmed by the disadvantageous effect on the PACU.

Hypothesis 4 [LCF] : Matching the simulation results, sequencing by LCF at the study hospital would result in increased PACU staffing requirements.

Although sequencing cases to reduce delays in PACU admission can be advantageous for a hospital and anesthesia group, few surgeons would be affected directly, because preference for a PACU bed should go to patients in ORs with subsequent scheduled cases (1,8). Thus, we speculated that a way to encourage surgeons to adjust sequencing of their patients would be by showing them and their schedulers how sequencing can reduce their patients' average waiting from scheduled start times (9). When other constraints are not relevant, each surgeon's list of cases would be sequenced with the surgeon's most predictable case first, second most predictable case second, and so forth (9). Although there are exceptions for individual surgical cases (9), overall for the surgical suite this would be similar to SCF (10). Resistance to our plan arose from nursing concerns that the routine use of SCF or similar sequencing methods would require more holding area nurses to prevent delays in OR admissions.

Hypothesis 5 [SCF] : Sequencing cases by SCF would not significantly increase holding area staffing requirements for the study hospital, because there are many ORs and the surgeons have cases of different durations.

METHODS

Historical data were obtained from a 10 OR French hospital surgical suite without any policy for case

Table 2. Simple Example of How Case Sequencing Affects Postanesthesia Care Unit (PACU) Staffing Requirements

Sequencing method	OR	Duration of each case in each OR (h)	Times of PACU admission from each OR (h)	Patients in the PACU from each OR at each of 11 consecutive hours	Overall peak number of patients in PACU
LCF	OR A	3, 2, 1	3, 5, 6	0, 0, 1, 1, 1, ***2***, 1, 0, 0, 0, 0	6 for LCF
	OR B	3, 2, 1	3, 5, 6	0, 0, 1, 1, 1, ***2***, 1, 0, 0, 0, 0	
	OR C	3, 2, 1	3, 5, 6	0, 0, 1, 1, 1, ***2***, 1, 0, 0, 0, 0	
MIX	OR A	1, 3, 2	1, 4, 6	1, 1, 0, ***1***, 1, 1, 1, 0, 0, 0, 0	3 for MIX
	OR B	1, 3, 2	1, 4, 6	1, 1, 0, ***1***, 1, 1, 1, 0, 0, 0, 0	
	OR C	1, 3, 2	1, 4, 6	1, 1, 0, ***1***, 1, 1, 1, 0, 0, 0, 0	

Read the table from left to right, one row at a time. The listed methods of case sequencing in the first column are described and defined in Table 1. For simplification, turnover times were excluded. The table matches the upper half of Table 4. The times of admission into the PACU in the fourth column were calculated by sequentially adding the case durations in the preceding column. The resulting number of patients in the PACU at each hour (fifth column) was calculated using a PACU duration fixed at 2 h. The peak of the sum of the number of patients from each OR in the PACU is the value given in the sixth column.

LCF = longest cases first and MIX = mixture of case durations (Table 1).

Table 3. Characteristics of the Studied Hospital Surgical Suite: Its Operating Rooms (ORs), Surgeons, and Cases

	Mean ± standard deviation	Median ± quartile deviation	Sample size (*N*)
OR days each surgeon works	46 ± 40	34 ± 36	50 surgeons
Surgeons per day	11.5 ± 2.7	12.0 ± 1.5	201 days
Surgeons per day performing all of his or her cases in one OR	11.0 ± 2.5	11.0 ± 1.5	201 days
Surgeons per day performing his or her cases in two ORs	0.5 ± 0.7	0.0 ± 0.5	201 days
Cases per OR per day	5.1 ± 2.9	5.0 ± 1.5	10 rooms, 201 days
Cases per surgeon working each day	3.9 ± 2.4	4.0 ± 1.8	2219 surgeon days
Durations (OR min)	67 ± 56	51 ± 28	8724 cases

sequencing (Table 3). The data spanned 201 consecutive workdays in 2005. The data used were the OR in which each case was performed, the dates and times of patient entry and exit from the OR, and the surgeon who performed the case.

For each of the 50 surgeons, the number of workdays was calculated that he or she either: (a) performed one case, (b) used SCF, (c) used LCF, (d) used MIX, or (e) used another sequence for three or more cases. These categories were exclusive (Table 1). To test Hypothesis 1 [observational], the Pearson χ^2 test was used to test for homogeneity of use of each sequencing method among days. The χ^2 test was also used to test for homogeneity of use of each sequencing method among surgeons. *P* values were calculated using exact methods (StatXact-7, Cytel Software Corporation, Cambridge, MA).

Impact of Case Sequencing on the PACU and Holding Area

The statistical analysis of the historical data was performed using discrete-event simulation (Fig. 1).

As sequencing of the data can affect setup and cleanup times, "wheels out" to "wheels in" turnover times were generated randomly with a two-parameter lognormal distribution, mean ± SD = 0.50 ± 0.25 h, bounded between 0.083 h and 1 h. Analysis was repeated using a fixed turnover time of 0.50 h.

The actual case duration was considered to equal the scheduled case duration, because our objective was not to study the accuracy of case scheduling at the study hospital, but to draw conclusions applicable to many facilities. Previous studies showed that inaccuracy in case durations minimally affects the impact of case sequencing on PACU staffing (2,7). Nevertheless, we repeated the analysis with imprecision. Each observed case duration was multiplied by a normally distributed random number with a mean of 1.0 and a standard deviation that was itself a normally distributed random number with mean 0.25 and standard deviation 0.05 (7). The product was bounded between 0.334 h and 7.5 h. The standard deviation was variable to represent the observed, realistic heterogeneity among cases in proportional variability between scheduled and actual durations (9).

The peak number of patients in the PACU drives the staffing requirement (1,7,11). For each sequencing method and for each of the 201 days, the number of patients in the PACU was calculated in 1 min intervals from the start of each workday. The peak number of patients in the PACU was calculated for each method and day. Then, for each day, we calculated the pair-wise differences in the peak numbers of patients among the sequencing methods. For every pair-wise comparison of sequencing methods, the median pair-wise difference in the peak number of patients was calculated (i.e., the 101st of the 201 workdays sorted in ascending sequence of pair-wise differences). The 95% distribution free confidence interval was the 86th and 115th values (StatXact-7). This method (12) was used to calculate confidence intervals because it was appropriate when there were many small differences between sequencing methods (e.g., 35 values of −1, 90 values of 0, and 76 values of 1).

Data from Additional Hospitals

Table 4 shows that when ORs have different total hours of cases, the incremental benefit of sequencing each OR individually can be reduced. As a sensitivity analysis, we estimated the study hospital's standard deviation among ORs in the daily total hours of cases including turnover times between 7:00 AM and 11:00 PM (13). Standard deviations were also calculated for a simulated hospital using parameter values studied previously (7) and 33 other hospitals from the United States and Australia. The 33 hospitals had 1010 to 19,940 cases (median 10,750 quartile deviation 2880) and 410 to 7240 combinations of OR and workday (median 2980 quartile deviation 1170).

Confidence intervals were calculated as follows. For each workday and OR, the daily total hours of cases including turnovers was calculated. The standard deviation and number of ORs with cases were calculated for each day. The confidence interval equals the ratio of the fixed effects analysis of variance sum squared error to the inverse of the appropriate χ^2 distribution (13). Systat 11.0 was used for the calculations (Systat Software, San Jose, CA). There was homogeneity of the standard deviations among days for each facility (all *P* values were >0.16 by Levene's test).

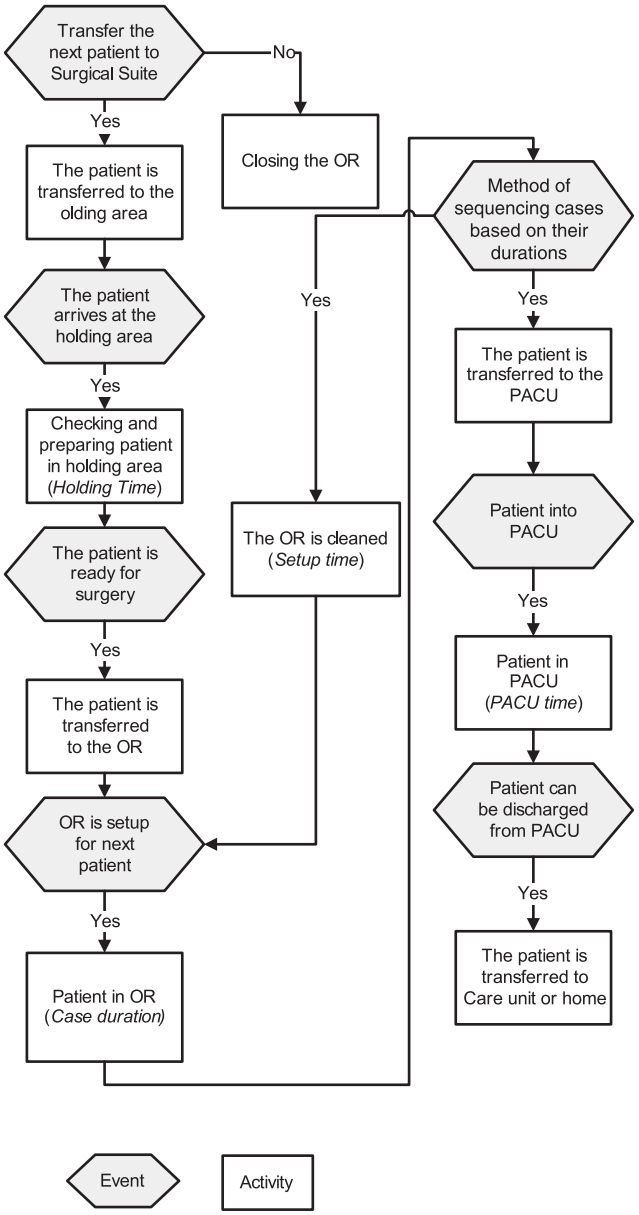

Figure 1. Flowchart of the discrete-event simulation used to analyze the impact of case sequencing on the postanesthesia care unit (PACU). The software used was ARENA version 8.00, Rockwell Software, Sewickley, PA. Each surgeon's list of cases in the same operating room (OR) on the same day was sequenced using one of the methods listed in Table 1. Because there were 201 workdays, we performed 201 simulations. The probability distributions for the turnover time and for scheduled/actual case durations are given in the Methods. Other random variables are listed in the Table captions. The end-point of each simulation was the median pair-wise difference among sequencing methods in the peak numbers of patients in the PACU. If the peak number of patients were reduced, then either (a) PACU staffing could be reduced without an increase in delays in PACU admission or (b) delays in PACU admission could be reduced without an increase in PACU staffing.

RESULTS

Hypothesis 1 [Observational] : The surgeons differed among themselves in their sequencing of cases based on the cases' durations ($P < 10^{-8}$) (Table 5). Each day's most common sequence accounted for only 44% of surgeon-OR-day combinations. The surgeons were also internally heterogeneous, whether by being non-systematic and/or having many constraints. Each surgeon's most common method of sequencing cases based on their durations accounted for only 51% of his or her OR-day combinations (Table 5), but some surgeons were far more or less heterogeneous than others (Fig. 2).

Hypothesis 2 [Random] : The original sequence of surgeons was functionally the same as a random sequencing of cases (Table 6, row 4).

Hypothesis 3 [MIX] : The best previously identified method (7), MIX, was no better in practice at reducing PACU staffing requirements than was the current uncoordinated sequencing (Table 6, Row 3).

Hypothesis 4 [LCF] : Contrary to previous simulation results (7), the poor performance of LCF versus MIX was mitigated at the study hospital (Table 6, Row 6).

This finding could not be explained by all cases having similar durations, as that was not the situation. The standard deviation of case durations at the study hospital was 0.9 h, not substantively different from the 1.2 h in the simulations. Furthermore, both of these standard deviations were in the lower quintile of values at 33 other hospitals (Fig. 3), not just the study hospital, as would be needed for this finding to explain the results.

We explored another source of mitigation of the benefit of sequencing methods over LCF. In the simulations (7), the standard deviation of the hours of cases including turnovers in each OR was 1.4 h. This value is realistic when cases with overall average scheduled durations of 2 h are scheduled to fill each OR's 8 h workday. However, at the study hospital, some ORs were much busier than others on the same day. The standard deviation was 3.2 h (95% confidence interval 3.1 to 3.3 h) (13). Mitigation of the disadvantageous effect of LCF occurred by having some ORs with much briefer work hours than some other ORs (Table 4).

To evaluate whether such heterogeneity in workload among ORs is commonplace at hospital surgical suites, data from 33 other hospitals were analyzed. In practice, these hospitals did not have all ORs fully packed with the same end of the workday (Figs. 4 and 5) (6). Instead, some ORs had under-utilized OR time and other ORs had over-utilized OR time; some ORs had 8 h allocations and other ORs had longer hours of allocated time; and/or some ORs finished before the end of an 8 h workday and other ORs were used for urgent cases, not finishing until late in the evening (6,8). For readers who work at hospitals with one or more of these characteristics, our article shows that independent sequencing of different surgeons' lists of cases is unlikely to affect PACU staffing.

Hypothesis 5 [SCF] : The different methods of case sequencing affect the time of the day of the peak numbers of patients in the holding area, but not the

Table 4. Example of How Heterogeneity in Operating Room (OR) Workload Affects the Sensitivity of Postanesthesia Care Unit Staffing Requirements on the Method of Case Sequencing

Standard deviation of OR duration	Sequencing method	OR	Duration of each case in each OR (h)	Times of PACU admission from each OR (h)	Patients in the PACU from each OR at each of 11 consecutive hours	Overall peak number of patients in PACU
0.0 h						
ORs are same	LCF	A	3, 2, 1	3, 5, 6	0, 0, 1, 1, 1, ***2***, 1, 0, 0, 0, 0	6 for LCF
		B	3, 2, 1	3, 5, 6	0, 0, 1, 1, 1, ***2***, 1, 0, 0, 0, 0	
		C	3, 2, 1	3, 5, 6	0, 0, 1, 1, 1, ***2***, 1, 0, 0, 0, 0	
	MIX	A	1, 3, 2	1, 4, 6	1, 1, 0, ***1***, 1, 1, 1, 0, 0, 0, 0	3 for MIX
		B	1, 3, 2	1, 4, 6	1, 1, 0, ***1***, 1, 1, 1, 0, 0, 0, 0	
		C	1, 3, 2	1, 4, 6	1, 1, 0, ***1***, 1, 1, 1, 0, 0, 0, 0	
3.0 h						
As in Figure 3	LCF	A	3, 2, 1	3, 5, 6	0, 0, ***1***, 1, 1, 2, 1, 0, 0, 0, 0	4 for LCF
		B	2, 1	2, 3	0, 1, ***2***, 1, 0, 0, 0, 0, 0, 0, 0	
		C	3, 3, 2, 1	3, 6, 8, 9	0, 0, ***1***, 1, 0, 1, 1, 1, 2, 1, 0	
	MIX	A	1, 3, 2	1, 4, 6	1, ***1***, 0, 1, 1, 1, 1, 0, 0, 0, 0	3 for MIX
		B	1, 2	1, 3	1, ***1***, 1, 1, 0, 0, 0, 0, 0, 0, 0	
		C	1, 3, 2, 3	1, 4, 6, 9	1, ***1***, 0, 1, 1, 1, 1, 0, 1, 1, 0	

Read the table from left to right, one row at a time. The listed methods of case sequencing in the second column are described and defined in Table 1. The standard deviation of 0.0 h had three cases in each OR, one 1 h, one 2 h, and one 3 h. These cases are shown in the third (OR) and fourth (Duration) columns. For simplification, turnover times were excluded. The upper half of the table matches Table 2. The standard deviation of 3.0 h was produced by moving the 3 h case from OR B to OR C, shown in the bottom six rows of the third and fourth columns. The times of admission into the postanesthesia care unit (PACU) in the fifth column were calculated by sequentially adding the case durations in the preceding column. The resulting number of patients in the PACU at each hour (sixth column) was calculated using a PACU duration fixed at 2 h. The peak of the sum of the number of patients from each OR in the PACU is the value given in the seventh column. The increase in the standard deviation causes a reduction in the peak PACU workload with LCF from six to four patients, but no change for MIX.

LCF = longest cases first and MIX = mixture of case durations (Table 1).

Table 5. Observed Distribution of Use of the Sequencing Methods

Sequence	Percentage	95% confidence interval
Single	22	20–24
LCF	14	13–16
SCF	10	9–11
MIXture of case durations	3	2–3
Sequence of three or more cases other than MIX	51	49–53
Each day's most common surgeon–OR sequence	44	42–46
Each surgeon's most common OR–day sequence	51	49–53

The "Percentage" refers to the use of the sequencing method in Table 1 among each list of one surgeon's cases in the same operating room (OR) on the same day. The abbreviations and definitions are given in Table 1. The numbers of workdays, surgeons, cases, etc., are given in Table 3. The "Percentage" was based on the $N = 2219$ lists of a surgeon's cases in the same OR on the same day. There were no differences among the 201 workdays in the frequency of use of the different sequencing methods ($P = 0.46$). Because there were similar numbers of sequences that were LCF and SCF, there was a functionally homogeneous flow into the postanesthesia care unit and holding area from those ORs.

LCF = longest cases first; SCF = shortest cases first and MIX = mixture of case durations (Table 1).

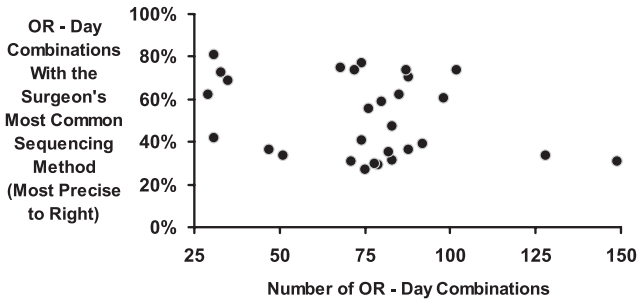

Figure 2. Although overall each surgeon's most common sequence accounted for 51% of his or her operating room (OR)–day combinations (Table 4), there was marked heterogeneity among surgeons. The figure does not show 50 unique circles, because some of the surgeons' values overlap.

peak itself (i.e., the staffing requirements) (Table 7).

DISCUSSION

The effective rate of exit of patients from ORs to a PACU can be sufficiently close to random (Table 5) that the independent sequencing of surgeons' lists of cases (7) (Table 1) can have little incremental benefit on reducing PACU staffing or, equivalently (1,7), preventing delays in PACU admission (Table 6). The same applies to the holding area (Table 7). The commonplace (Figs. 4 and 5) heterogeneity among hospitals' ORs in the durations of the workday results in a large and important mitigation of the effect of sequencing on the PACU (Table 6).

Among strategies to reduce delays in admission from ORs into PACUs, the most effective at hospitals has been adjustment of PACU nurses' staff scheduling a few months before the day of surgery to match the observed timing of admissions from the ORs (1,3–5). The implication of our article is strengthening of the evidence for OR and PACU managers that primary efforts to reduce delays in PACU admission should be by matching staffing and beds to workload using statistical optimization (1,3–5). Many hospitals will find it hard to achieve benefits from the use of case sequencing as a way to reduce PACU and holding area staffing requirements.

Table 6. Effect of Surgeons' Heterogeneous Case Sequencing on Postanesthesia Care Unit (PACU)

	1 h	2 h	Log normal	Different scheduled and actual durations	Turnover time fixed at 0.5 h
Orig. versus LCF	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 1)	0 (−1 to 0)
Orig. versus SCF	−1 (−1 to −1)	−1 (−1 to −1)	−1 (−1 to 0)	−2 (−2 to −1)	−2 (−2 to −2)
Orig. versus MIX	0 (−1 to 0)	0 (0 to 0)	0 (0 to 0)	0 (−1 to 0)	0 (0 to 1)
Orig. versus Random	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (−1 to 0)
LCF versus SCF	−1 (−1 to −1)	−1 (−1 to −1)	−1 (−1 to 0)	−2 (−2 to −2)	−2 (−2 to −2)
LCF versus MIX	0 (−1 to 0)	0 (0 to 0)	0 (0 to 0)	0 (−1 to 0)	1 (0 to 1)
LCF versus Random	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
SCF versus MIX	0 (0 to 0)	1 (1 to 1)	1 (0 to 1)	1 (1 to 1)	3 (2 to 3)
SCF versus Random	1 (0 to 1)	1 (1 to 1)	0 (0 to 1)	2 (1 to 2)	2 (2 to 2)
MIX versus Random	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 1)	−1 (−1 to 0)

The table shows the median (95% confidence interval) of pair-wise differences in the daily peak numbers of patients in the PACU. The study hospital's actual PACU lengths of stay were not used, because they were appropriately affected by managerial decision-making made by clinicians on the day of surgery (1,16). The "Log normal" distribution model of PACU duration in minutes was min (240, max (30, 5 × int (ln (60.0, 72.0)/5))). The "Different scheduled and actual durations" and "Turnover time fixed at 0.5 h" were performed with a 2 h PACU length of stay. The "Turnover time fixed at 0.5 h" column is deterministic, showing intentionally unrealistic results when no variability is included other than day to day variability in daily cases. For example, "Orig. versus Random" in row four shows that for all conditions the original sequence of surgeons was functionally the same as a random sequencing of cases, as explored by *Hypothesis 2* [*Random*]. "LCF versus MIX" in row six shows that only when there is no variability does LCF differ in its performance from MIX, as explored by *Hypothesis 4* [*LCF*].

LCF = longest cases first; SCF = shortest cases first and MIX = mixture of case durations (Table 1).

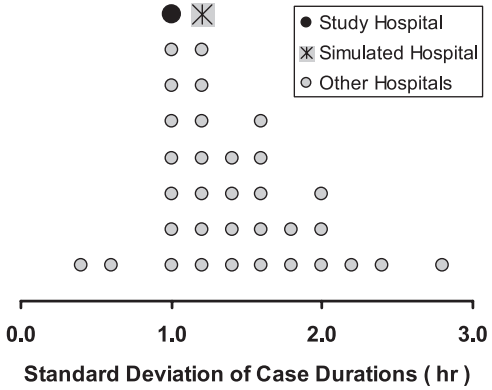

Figure 3. Standard deviation of case durations at the study hospital, previous simulations (1), and at 33 other hospitals.

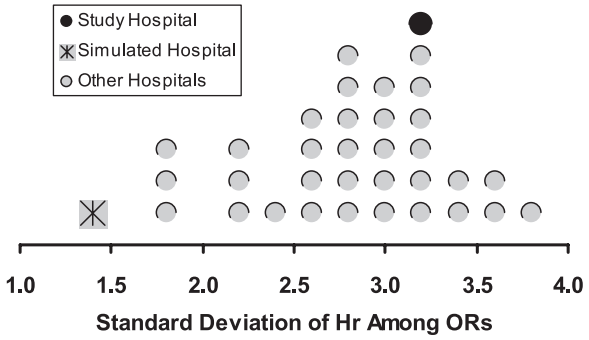

Figure 4. Standard deviations among operating rooms (ORs) in the daily total hours of cases including turnover times between 7:00 AM and 11:00 PM. Standard deviations are reported for the studied hospital, a simulated hospital using parameter values as studied previously (7), and 33 other hospitals. The standard deviations are shown with a simple dot plot, but without confidence intervals. In Figure 5, the same data are shown in a league table, with confidence intervals.

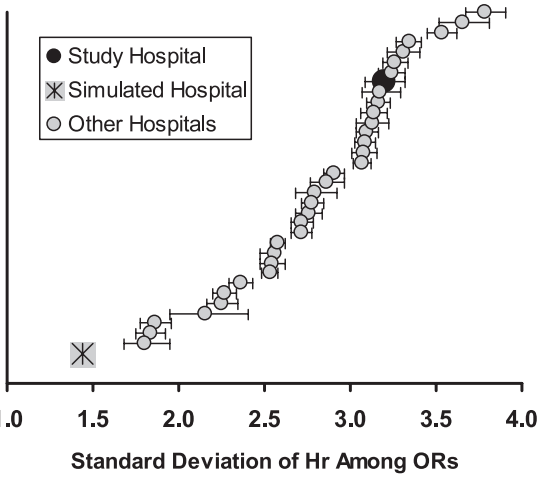

Figure 5. Standard deviations among operating rooms (ORs) in the daily total hours of cases including turnover times between 7:00 AM and 11:00 PM. Standard deviations are reported for the studied hospital, a simulated hospital using parameter values as studied previously (7), and 33 other hospitals. The standard deviations are shown in a league table, with confidence intervals. In Figure 4, the same data are shown with a simple dot plot, but without confidence intervals.

Sequencing All Scheduled Cases Simultaneously

We studied the independent sequencing of each surgeon's list of cases (7). An alternative approach to case sequencing is to perform the sequencing the working day before surgery (1,2,14). Once each surgeon's list of cases has been assigned to an OR and the OR nurses and anesthesia providers have been assigned to ORs, then each surgeon's list of cases is sequenced, and the final OR schedule published (2). An advantage of this approach is that relationships among sequences are considered, providing the lowest possible incidence of delays in PACU and/or holding area admission (1,7). A disadvantage is that the computer doing the sequencing must know the constraints to changing the sequences of cases (2). Because most of the constraints are relative criteria, not absolute, communicating their relative importance ahead of time to a computer and/or office can be problematic.

Table 7. Effect of Surgeons' Heterogeneous Case Sequencing on Holding Area

	10 min	20 min	30 min	Different scheduled and actual durations
Orig. versus LCF	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Orig. versus SCF	0 (0 to 0)	−1 (−1 to 0)	−1 (−1 to −1)	−1 (−1 to −1)
Orig. versus MIX	0 (0 to 0)	0 (−1 to 0)	−1 (−1 to 0)	−1 (−1 to 0)
Orig. versus Random	0 (0 to 0)	0 (0 to 0)	0 (−1 to 0)	0 (−1 to 0)
LCF versus SCF	0 (0 to 0)	−1 (−1 to 0)	−1 (−1 to −1)	−1 (−1 to −1)
LCF versus MIX	0 (0 to 0)	0 (−1 to 0)	−1 (−1 to 0)	−1 (−1 to −1)
LCF versus Random	0 (0 to 0)	0 (0 to 0)	0 (−1 to 0)	0 (−1 to 0)
SCF versus MIX	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	1 (0 to 1)
SCF versus Random	0 (0 to 0)	1 (0 to 1)	1 (0 to 1)	1 (0 to 1)
MIX versus Random	0 (0 to 0)	1 (0 to 1)	0 (0 to 1)	0 (0 to 0)

The table shows the median (95% confidence interval) of pair-wise differences in the daily peak numbers of patients in the holding area at the study hospital. The "Different scheduled and actual durations" was performed with a 20-min time in the holding area. The patient was called by each operating room (OR) "just in time" for surgery. The use of constant durations in the holding area deliberately over-estimated effects of sequencing, by not considering the appropriate preemption of tasks in the holding area to take the patient to the OR and to complete tasks there.
LCF = longest cases first; SCF = shortest cases first and MIX = mixture of case durations (Table 1).

For example, a surgeon works in a subspecialty for which intensive care unit (ICU) transfer directly from the OR is common, and for which transferring patients from the ICU often occurs later in the workday. Then, patients undergoing surgery first should generally be those in the ICU preoperatively or patients who are unlikely to be admitted to the ICU. The computer would need to know each patient's preoperative location and probability of ICU admission.

For example, a surgeon is planning a patient to be the first case of the day, because a surgical fellow will be available then, but not later in the day, since the fellow will participate in the third case of the day in a different OR. The computer would need to know that the surgical fellow will participate in both cases and the portions of the cases that participation is required.

We personally have been unsuccessful at implementing the simultaneous sequencing of ORs because of the challenges in communicating the relevant constraints.

Consequently, we explored the independent sequencing of each surgeon's list of cases (7). The person doing the scheduling can request any additional information that is needed as soon as each new patient is added. The computer can simply provide a recommendation, instead of forcing the resequence, making it unnecessary for the computer to know most constraints. However, the approach seems of limited value (Tables 6 and 7).

Likely, none of the above limitations apply to small facilities (2) or to surgical suites' pods with a few ORs and a mini-PACU (15). At such specialized facilities, sequencing cases may be beneficial for PACU staffing. For the typical four OR ambulatory surgery center with each OR filled with cases from 7 AM to 1 PM and finishing between 1 PM and 2:30 PM, case sequencing is a good approach to reducing PACU staffing requirements (2). The preceding statistical methods to match PACU staffing to workload (1,3–5) are unnecessary, because there will be a few PACU nurses and their appropriate shifts will be obvious.

Factors Excluded from Consideration

Our assessments of case sequencing ignored limitations due to the need for some patients to receive care early in the day for safety reasons (e.g., Type I diabetics sequenced first). Therefore, our analysis *overestimated* the incremental differences among sequencing methods in affecting PACU and holding area staffing. The fact that the differences we detected were so small anyway reinforces the likelihood of our results being applicable to other hospitals.

Our assessments of case sequencing ignored the occasional need to coordinate sequencing among ORs because of limited equipment or personnel. A personnel example is in the preceding section. Another common example is the use of a surgical microscope for the first case of the day in one OR and for the second case of the day in another OR (8,9). By neglecting such resource constraints, our analysis *overestimated* the incremental differences among sequencing methods in affecting PACU and holding area staffing.

Our assessments of case sequencing ignored the scenario of the single surgeon switching between two ORs, with two anesthesia providers and teams of OR nurses. By neglecting the effective constraint, our analysis *overestimated* the incremental differences among sequencing methods in affecting PACU and holding area staffing.

Finally, our assessments of case sequencing ignored decision-making on the day of surgery to reduce overutilized OR time (e.g., moving cases and assigning add-on cases) (8). In addition, some of the surgeons' cases that we sequenced were add-on cases and so could not have had their start times changed. Because all such decisions would have appropriately disrupted the planned case sequencing, again, our analysis *overestimated* the incremental differences among sequencing

methods. Thus, our findings of few differences among methods for sequencing surgeons' cases on the PACU and holding area likely apply to many hospitals.

CONCLUSIONS

The uncoordinated decision-making of multiple surgeons working in different ORs can result in a sufficiently uniform rate of admission of patients into the PACU and holding that the independent sequencing of each surgeon's list of cases would not reduce the incidence of delays in admission or staffing requirements. Best evidence for such operational improvements at large PACUs and holding areas remains the use of optimization for matching staffing and beds to the workload, instead of trying to change the workload to match the staffing (1,3–6).

REFERENCES

1. Dexter F, Epstein RH, de Matta R, Marcon E. Strategies to reduce delays in admission into a postanesthesia care unit from operating rooms. J Perianesth Nurs 2005;20:92–102.
2. Hsu VN, de Matta R, Iee CY. Scheduling patients in an ambulatory surgical center. Nav Res Logist 2003;50:218–38.
3. Dexter F, Epstein RH, Penning DH. Statistical analysis of post-anesthesia care unit staffing at a surgical suite with frequent delays in admission from the operating room—a case study. Anesth Analg 2001;92:947–9.
4. Epstein RH, Dexter F, Traub RD. Statistical power analysis to estimate how many months of data are required to identify post anesthesia care unit staffing to minimize delays in admission from operating rooms. J Perianesth Nurs 2002;17:84–8.
5. Dexter F, Wachtel RE, Epstein RH. Impact of average patient acuity on staffing of the phase I PACU. J Perianesth Nurs 2006;21:303–10.
6. McIntosh C, Dexter F, Epstein RH. Impact of service-specific staffing, case scheduling, turnovers, and first-case starts on anesthesia group and operating room productivity: tutorial using data from an Australian hospital. Anesth Analg 2006;103:1499–516.
7. Marcon E, Dexter F. Impact of surgical sequencing on post anesthesia care unit staffing. Health Care Manag Sci 2006;9:87–98.
8. Dexter F, Epstein RD, Traub RD, Xiao Y. Making management decisions on the day of surgery based on operating room efficiency and patient waiting times. Anesthesiology 2004;101:1444–53.
9. Dexter F, Ledolter J. Bayesian prediction bounds and comparisons of operating room times even for procedures with few or no historical data. Anesthesiology 2005;103:1259–67.
10. Lebowitz P. Schedule the short procedure first. AORN J 2003;78:651–8.
11. Dexter F, Tinker JH. Analysis of strategies to decrease post anesthesia care unit costs. Anesthesiology 1995;82:94–101.
12. Hahn GJ, Meeker WQ. Statistical intervals—a guide for practitioners. New York: Wiley, 1991:78:82–83.
13. Searle SR, Casella G, McCulloch CE. Variance components. New York: Wiley, 1992:44:69–72, 77.
14. Jebali A, Alouane ABH, Ladet P. Operating rooms scheduling. Int J Prod Econ 2006;99:52–62.
15. Sokal SM, Craft DL, Chang Y, Sandberg WS, Berger DL. Maximizing operating room and recovery room capacity in an era of constrained resources. Arch Surg 2006;141:389–95.
16. Dexter F, Traub RD, Penning DH. Statistical analysis by Monte-Carlo simulation of the impact of administrative and medical delays in discharge from the post-anesthesia care unit on total patient care hours. Anesth Analg 2001;92:1222–5.