

A Simulation Model for Determining the Optimal Size of Emergency Teams on Call in the Operating Room at Night

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BACKGROUND: Hospitals that perform emergency surgery during the night (e.g., from 11:00 PM to 7:30 AM) face decisions on optimal operating room (OR) staffing. Emergency patients need to be operated on within a predefined safety window to decrease morbidity and improve their chances of full recovery. We developed a process to determine the optimal OR team composition during the night, such that staffing costs are minimized, while providing adequate resources to start surgery within the safety interval.

METHODS: A discrete event simulation in combination with modeling of safety intervals was applied. Emergency surgery was allowed to be postponed safely. The model was tested using data from the main OR of Erasmus University Medical Center (Erasmus MC). Two outcome measures were calculated: violation of safety intervals and frequency with which OR and anesthesia nurses were called in from home. We used the following input data from Erasmus MC to estimate distributions of all relevant parameters in our model: arrival times of emergency patients, durations of surgical cases, length of stay in the postanesthesia care unit, and transportation times. In addition, surgeons and OR staff of Erasmus MC specified safety intervals.

RESULTS: Reducing in-house team members from 9 to 5 increased the fraction of patients treated too late by 2.5% as compared to the baseline scenario. Substantially more OR and anesthesia nurses were called in from home when needed.

CONCLUSION: The use of safety intervals benefits OR management during nights. Modeling of safety intervals substantially influences the number of emergency patients treated on time. Our case study showed that by modeling safety intervals and applying computer simulation, an OR can reduce its staff on call without jeopardizing patient safety.

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Nighttime surgical schedules allow for fewer surgical cases than daytime surgical schedules. Irregular-hour payments and work-sleep regulations for operating room (OR) staff contribute to higher costs during the night. Facing OR staff shortages, OR suite managers must critically appraise nighttime workforce deployment.¹

Appropriate size of the emergency team, with acceptable frequency of calling team members from home, should ensure sound treatment for all patients. Previous studies show that analytical methods can

help determine numbers of OR and anesthesia nurses needed.²⁻⁷ It has been shown that the labor costs of emergency teams during regular hours, second shifts, and weekends can be significantly reduced, but most authors exclude the night shift,⁷⁻⁹ or focus on single specialty OR suites.²⁻⁴ These studies implicitly assume that all patients are operated upon at the time that they were actually scheduled for surgery, without considering the option of postponing surgery within a predefined safety interval. For example, a facility may consider it imperative for a patient with a ruptured abdominal aortic aneurysm to be operated on within 30 min of arrival, while a patient with an amputated finger should be operated on within 90 min of arrival, and a patient with a perforated gastric ulcer should be operated on within 3 h of arrival. Although studies have defined safety intervals for emergency surgery during the day,¹⁰ the option of postponing operations by a safe time interval during the night shift has not yet been addressed.

Dexter and O'Neill propose a statistical method to determine the weekend staffing requirement of the OR suite.⁷ It assumes an expected workload and

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Table 1. Data Per Surgical Department Over All Night Shifts in the Period 1994–2004 at the Main OR Suite of Erasmus MC

Surgical department	Proportion of all surgical cases (%)	Duration of surgical case (min)		Proportion of ICU patients (%)
		Mean	Variance	
General surgery ^a	47.1	156.16	118.45	15.6
Traumatology ^b	15.9	146.14	82.10	2.7
Neurosurgery	15.5	126.24	72.32	28.6
Plastic surgery	9.9	200.32	142.45	10.6
Gynecology	7.2	74.05	41.02	3.7
ENT surgery ^c	4.4	90.21	54.88	10

OR = operating room; ICU = intensive care unit; Erasmus MC = Erasmus University Medical Center.

^a Including vascular and transplant surgery.

^b Including emergency orthopaedic surgery.

^c Ear nose throat surgery.

computes the staffing requirements based on this workload. However, it does not incorporate safety intervals that might level the workload, hence reduce numbers of staff to be called in from home.

Tucker et al. proposed a queuing approach to determine OR staff requirements.⁶ This approach does not address the issue of treating patients on time. In addition, the authors do not incorporate detailed characteristics of surgical departments and the OR suite. This approach, therefore, typically over-estimates the probability of multiple cases being performed at the same time, since no delaying of cases within their safety intervals was considered. The method, just like that of Dexter et al.¹¹ is deliberately conservative.

Our study was designed to determine optimal OR staff on call at nights by explicit modeling of patients' safety intervals and by discrete-event simulation modeling. The simulation model provided insight into the trade-off between the main outcome measures of providing surgery on time and calling in team members from home. A case study was performed for the main OR suite of Erasmus Medical Center Rotterdam (Erasmus MC).

METHODS

Erasmus MC is a tertiary referral center that has maintained a database with information on all surgical cases since 1994. The information includes duration of the various cases, the surgeon and surgical department involved, the exact nature of the cases, patient arrival time, and the composition of the surgical and anesthesia team present for each case. Anesthesia and surgery nurses prospectively approved these data immediately after a surgical case and surgeons retrospectively approved all data.

In this study we used a discrete simulation model to determine the optimal size of emergency teams (i.e., anesthesia and surgery nurses) on call at night. The model involves several issues already addressed by others, including sequencing of emergency patients¹² and determination of staff requirements.^{2,3,13} Our novel contribution is the additional modeling of medically sound safety intervals for emergency patients.

In anticipation of emergency cases, anesthesia and surgery nurses are on call either in the hospital or at home. For this study, the hours from 11:00 PM through 7:30 AM were defined as the night shift. We included the six surgical departments that yearly performed at least eight cases during the night shift. These are listed in Table 1, including data on surgical cases and intensive care unit (ICU) requirements.

We used simulation as a tool for analysis because of its ability to incorporate uncertain operating times and "what if" scenario analyses.^{10,14–16} Several earlier studies have used simulation successfully to assess the effects of staff reduction on patients' waiting times or staff requirements.^{2,3,12,13,17} The model was built in eM-Plant (Tecnomatix, Plano, TX) and comprised the following elements: (a) holding room, (b) ORs, (c) recovery room, (d) anesthesia nurses (either at home or in the OR suite) (e) surgery nurses (either at home or in the OR suite), and (f) patients.

Waiting times for emergency patients and the frequency of calling OR and anesthesia nurses from home were the primary outcome measures in this study. These measures combined with information on number of nurses on call in the hospital, provided insight into the costs of night shifts and the corresponding waiting time of emergency patients.

Modeling

The model started at the beginning of the night shift with an empty recovery room and no patients waiting for emergency surgery (i.e., an empty holding room). Recovery room capacity is unlikely to be a bottleneck in the process, since patients recovering from earlier evening shift cases are typically taken care of by evening shift nurses or recovery nurses. Hence, the assumption of an empty recovery room was valid. The model allowed for the possibility that evening shift cases (i.e., before 11:00 PM) were continuing after start of the night shift. We modeled this by assuming that at the start of the night shift there was a 40% likelihood that one OR was occupied and an 18% likelihood that two ORs were occupied, based on our case mix data. Remaining times of the surgical cases running into the

night shift were drawn from a lognormal distribution based on the same case mix data. Of course, these probabilities apply to Erasmus MC and should be adjusted by readers using numbers suitable for their facility.

We assumed that emergency patients arrive according to a Poisson distribution, which was modeled time-dependent. Table 2 shows the assumed interarrival times for each of the night shift hours, also expressed as mean number of patients arriving in a particular hour. Furthermore we assumed that each patient was instantly available for surgery (i.e., essential tests or scans already having been performed).

The type of surgical cases determined the composition of the team required to be present. At Erasmus MC, a large team of two anesthesia nurses and three surgery nurses is used for complex procedures (e.g., liver transplantation) and for unstable trauma patients. Other cases are staffed with one anesthesia nurse and two surgery nurses. Table 3 shows the proportion of cases requiring a large team for each surgical department. We did not incorporate anesthesiologists and surgeons in the model, since we assumed an adequate staffing of anesthesiologists and surgeons.

Upon arrival of a patient, the simulation checked the availability of ORs and the presence of the emergency team members. If both were available, the patient was operated on immediately. If too few emergency team members were available within the safety interval, the additional members were called in from home. Travel time was taken to be 30 min. We assumed that once assigned to a case, a nurse would be occupied for its duration.

Case durations were drawn from lognormal distributions¹⁸ for the surgical departments involved, based on the data set of the case under consideration (Table 1). After completion of the surgical case, team members called in from home were assumed to leave if no other patients were waiting or if the patients waiting did not require their attendance. Patients at this point were assigned to the ICU or the recovery room, given the probabilities in Table 1. Time needed to bring a patient to the ICU and to return to the OR was taken to be 30 min, which reflects an upper bound on transportation time during nighttime.

One anesthesia nurse assisting in the case transported the patient to the recovery room. There, at least two anesthesia nurses watched patients through the night, as required by Dutch Anesthesiology recommendations. If only one anesthesia nurse was assisting surgery and the recovery room was previously empty, the second nurse was called in from home on time, i.e., 30 min before the end of surgery. The recovery duration was drawn from a lognormal distribution using a historical mean of 70.2 min and a variance of 37.0 min. The surgery nurses were assumed to clean the OR and to restock materials after the surgical case. Figure 1 schematically depicts the simulation model.

Table 2. Mean Inter-Arrival Time of Emergency Patients During the Night Shift

Hour of the night shift	Inter-arrival times in minutes	Expressed in mean number of patients per hour
11:00 pm–0.00 am	175	0.34
0.01 am–1.00 am	204	0.29
1.01 am–2.00 am	520	0.12
2.01 am–3.00 am	656	0.09
3.01 am–4.00 am	1386	0.04
4.01 am–5.00 am	1782	0.03
5.01 am–6.00 am	1386	0.04
6.01 am–7.00 am	891	0.07
7.01 am–8.00 am	1040	0.06
Mean number of patients per night	—	1.1

Table 3. Proportions of Surgical Cases Requiring a Large Emergency Team

Surgical department	Percentage
General surgery ^a	30.0
Plastic surgery	35.4
Neurosurgery	0.0
Traumatology ^b	20.0
Gynaecology	17.0
ENT surgery ^c	0.0

^a Including vascular and transplant surgery.

^b Including emergency orthopedic surgery.

^c Ear nose throat surgery.

We determined four safety intervals based on clinical experience of the surgeons and OR staff in Erasmus MC. Then, based on a surgical department's patient mix and types of the cases we determined proportions of patients to be assigned to each of the four safety intervals. Table 4 shows these safety intervals for the six Erasmus MC surgical departments involved.

Precalculations

To benchmark results from the discrete-event simulation model we used the method developed by Dexter and O'Neill.⁷ Calculations were based on results from the staffing scenario that represented the current practice (Scenario 1, Table 5). This scenario was assumed "safe," seeing that in the past 10 yrs no emergency patients have been in severe danger because of OR staff shortage or lateness. Simpler methods such as Dexter and O'Neill's⁷ will reveal whether an OR suite acts on rational grounds.

Under Dutch Law, a nurse in-house during night shifts is paid 7.5% of the regular hourly daytime wage, while a nurse on call is paid 6% of the regular hourly daytime wage. A nurse working during the night shift is paid 47% more than the regular hourly daytime rate. Travel times of nurses on call are considered to be working time.

Scenarios

To evaluate compositions of emergency teams, we defined nine scenarios. Current practice in Erasmus

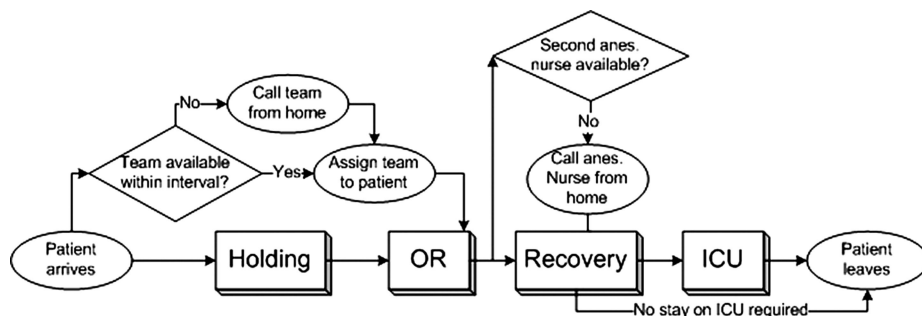


Figure 1. Concept process diagram of the simulation model.

Table 4. Proportions of Emergency Patients Per Surgical Department Assigned to the Four Safety Intervals

Safety intervals	General surgery ^a	Plastic surgery	Neurosurgery	Traumatology ^b	Gynecology	ENT surgery ^c
1. <30 min	15	0	74	15	26	33
2. <90 min	25	32	14	17	18	6
3. <3 h	20	18	10	24	21	29
4. <8 h	40	50	2	44	35	32

^a Including vascular and transplant surgery.

^b Including emergency orthopedic surgery.

^c Ear nose throat surgery.

MC (Scenario 1, Table 5) was used as the reference scenario against which we evaluated the other eight scenarios. In each subsequent scenario, one nurse was excluded from the night shift or placed on call at home instead of being present at the hospital. Scenarios with fewer staff than available in Scenario 9 were not considered, since these resulted in excessive waiting time for emergency patients.

We performed sensitivity analyses on the safety intervals. This allows comparison of our discrete-event simulation model with existing methods that do not deploy patient safety intervals. Five alternatives were analyzed. Each was constructed by excluding one or more safety intervals. The proportion of patients previously assigned to these intervals was distributed among the remaining safety intervals according to the original ratios. The following alternatives were defined:

1. Excluding safety intervals of 8 h;
2. Excluding safety intervals of 3 and 8 h;
3. Excluding safety intervals of 90 min, 3, and 8 h;
4. Excluding safety intervals of 30 min;
5. Excluding safety intervals of 30 min and 90 min.

Further sensitivity analyses were performed on the likelihood of recovery occupancy at 11:00 PM, the arrival intensity of patients during the night, and the likelihood of occupied ORs at 11:00 PM. We evaluated the following alternatives:

6. Likelihood of 50% recovery occupancy at 11:00 PM.
7. -10% arrival intensity
8. -20% arrival intensity
9. -30% arrival intensity
10. +10% arrival intensity
11. +20% arrival intensity
12. +30% arrival intensity

13. +25% likelihood of occupied ORs at 11:00 PM.
14. +50% likelihood of occupied ORs at 11:00 PM.
15. -25% likelihood of occupied ORs at 11:00 PM.
16. -50% likelihood of occupied ORs at 11:00 PM.

Based upon preliminary experiments we tested the alternatives for Scenarios 1 and 6. These two scenarios represented the interval from which Erasmus MC was likely to select its staffing level.

Before conducting the experiments, the model was validated by comparing the output of scenario 1 with actual practice. The key validation measure was number of times anesthesia or surgery nurses were called from home. Validation was provided by this number in the model being the same as in practice.

The number of runs required to obtain reliable results was determined by the following equation:

$$n_r^*(\gamma) = \min \left\{ i \geq n: \frac{t_{i-1, 1-\alpha/2} \sqrt{S^2(n)/i}}{|\bar{X}(n)|} \leq \gamma \right\},$$

Equation 1 Determination of the number of runs.¹⁹

Where $n_r^*(\gamma)$ is the minimum number of runs for obtaining a relative margin of error of γ , given an average value of $\bar{X}(n)$. The value $S^2(n)$ represents the variance of $\bar{X}(n)$ and α is the probability distribution of t , which is set at 0.05. A relative error of 0.1, which is a common value in simulation studies, yields 10,000 days.¹⁹ To measure patients' safety, we categorized amounts of time exceeding the safety interval in four categories: 0 to 10, 11 to 20, 21 to 30, and more than 30 min after the safety interval.

RESULTS

The method of O'Neill and Dexter⁷ applied to Scenario 1 showed that Erasmus MC could safely reduce the

Table 5. Scenarios of Emergency Team Compositions

Scenario	1	2	3	4	5	6	7	8	9
Number of anesthesia nurses (in-house + on call at home)	4 + 1	3 + 1	3 + 1	2 + 2	3 + 1	2 + 2	2 + 2	2 + 1	2 + 1
Number of surgery nurses (in-house + on call at home)	5 + 1	5 + 1	4 + 1	4 + 1	3 + 2	3 + 2	2 + 2	2 + 2	2 + 1

Table 6. Proportions of Emergency Patients Treated Too Late

Safety interval	SC1 (%)	SC2 (%)	SC3 (%)	SC4 (%)	SC5 (%)	SC6 (%)	SC7 (%)	SC8 (%)	SC9 (%)
Total too late	10.6	11.2	12.7	12.6	12.9	12.9	15.5	17.0	23.1
Between 0 min and 10 min too late	2.9	2.8	2.8	2.7	2.8	2.8	2.6	2.3	2.2
Between 10 min and 20 min too late	3.2	3.0	3.1	3.1	3.2	3.2	3.0	2.6	2.3
Between 20 min and 30 min too late	3.1	2.9	2.9	2.9	3.0	3.0	2.9	2.4	2.2
More than 30 min too late	1.4	2.4	3.9	4.0	3.9	3.9	7.1	9.7	16.4

SC = scenario.

number of anesthesia nurses by one. The resulting staffing level guarantees that in 95% of all night shifts sufficient staff are available using the actual times that patients waited for surgery. Reducing the number of anesthesia nurses by one yields Scenario 2. Applying the simulation methods, as presented in this paper, will achieve an additional reduction in the number of surgery nurses by letting patients wait longer for surgery, but not so long as to exceed the safety intervals.

Table 6 presents proportions of patients treated too late during the night shift. These computational results show a steady increase in total percentage from Scenario 1 (current situation) to 6. Scenarios 7, 8, and 9 show substantial increases in numbers of patients treated more than 30 min late. Reducing the numbers of anesthesia and surgery nurses following Scenarios 1 to 6 only slightly increases the proportion of patients treated too late. For instance, in Scenario 6 the percentage of patients treated 30 min after their safety intervals has increased by 2.5% relative to Scenario 1 (1.4% vs 3.9%). Correspondingly, the total percentage of patients treated too late has increased by only 2.3% in Scenario 6 (10.6% vs 12.9%).

Compared with the baseline Scenario the hospital can reduce overall staffing levels by one anesthesia nurse and one surgery nurse. In addition, Scenario 6 shows that one more anesthesia and one more surgery nurse can be allocated to take call from home instead of being in-house. Compared with Scenario 2 (outcome of method from O'Neill and Dexter⁷), Scenario 6 shows that Erasmus MC could reduce the overall staffing level by one surgery assistant. The extra reduction in overall staffing levels by our simulation method compared with the method of O'Neill and Dexter is due to the delay of some emergency patients within their safe waiting interval.

Figure 2 shows percentages of nights the first anesthesia nurse and the surgery nurse are called in from home in the different scenarios. Figure 3 shows this for the second nurses. The frequencies increase significantly beyond Scenario 4, then sharply decline for Scenario 9. In this scenario significantly more patients are postponed to the day team.

Tables 7 and 8 show the results of the sensitivity analyses. The sensitivity analysis in Scenario 3 (SA3) shows that setting all safety intervals to 30 min leads to a substantial increase of patients treated too late. In addition, SA1 to SA5 show that results are sensitive to the use of safety intervals. Accepting longer waiting times for all patients (SA4 and SA5) leads to a decline in the percentages of patients treated outside their safety intervals (Table 7). Occupancy of the recovery room at 23:00 h increases the number of patients who are treated late (SA6). Furthermore, outcomes are insensitive to variation in arrival intensity (SA7–SA12), but are sensitive to the number of occupied ORs at 23:00 h (SA13–SA16).

DISCUSSION

A simulation model was used to determine optimal size of the emergency team on call during the night, i.e., from 11:00 PM through 7:30 AM, using safety intervals for emergency patients. The main contribution of this study is that it combines aspects of patient safety, uncertainty of the case duration, and nocturnal OR staffing in a simulation approach.^{2,7,20} Although this is a single center study, variation of the input parameters showed that the approach can be generalized for use in other centers. To implement this approach, hospitals need to obtain data on patient arrival rates and safety intervals. Frequencies per safety interval can be computed by each surgical department.

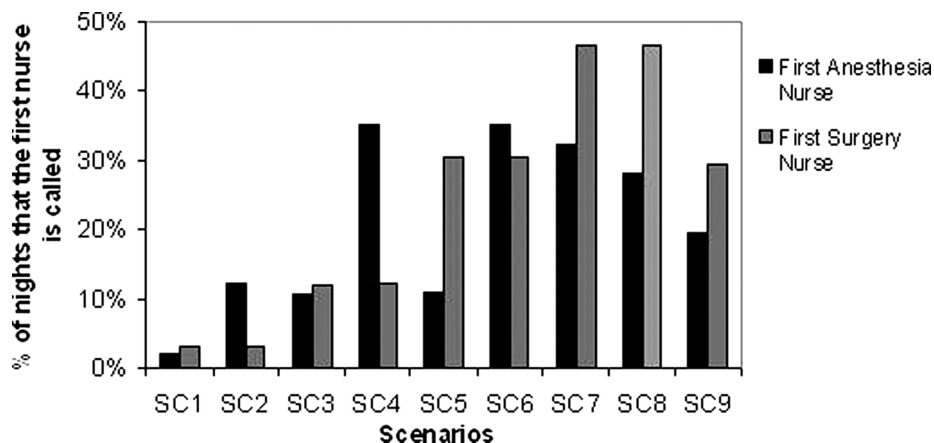


Figure 2. Proportions of nights in which the first nurses are called in from home.

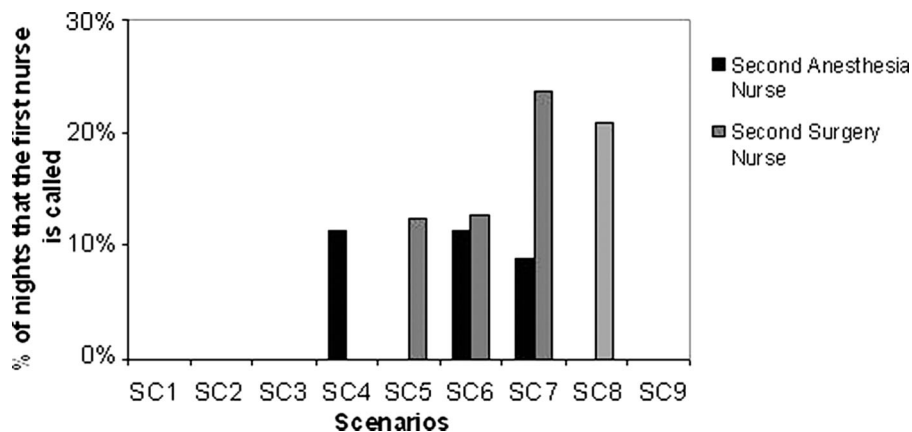


Figure 3. Proportions of nights in which the second nurses are called in from home.

The case study indicated that staffing, and thus cost, reductions may be realized for night shifts without jeopardizing patient safety. This is best illustrated in Scenario 6, which yields reduction of two in-house surgery nurses and two in-house anesthesia nurses as compared with Scenario 1. The consecutive Scenarios 7 to 9, with even greater reduction, are associated with substantial increase of patients being treated too late. The choice for Scenario 6 potentially makes two OR and two anesthesia nurses available for the daytime surgical schedules. Overall this would increase the productivity of the OR suite. Historically, the main OR suite in Erasmus MC deployed four anesthesia nurses and five surgery nurses during the night shift, forming two emergency teams permanently present in the OR suite. Statistics over the past 4 yrs, however, indicate a structural over-capacity of these teams. In 45% of the night shifts, no new patients were admitted for surgery after 11 PM. On average, 1.1 patients per night were operated on. In one of every seven nights, two teams had to work simultaneously to perform all emergency surgeries on time. Adopting the method of O'Neill and Dexter⁷ would have led to a change from Scenario 1 to Scenario 2, corresponding to an annual saving of approximately €70,000. Using a simulation approach, including the use of safety intervals, showed that changing from Scenario 1 to Scenario 6 in Erasmus MC is safe. Moreover, this reduction allows cutting night-shift costs by approximately 24%, corresponding to an annual cost reduction of €245,000. The

cost reduction is calculated by the same cost parameters used in the precalculations plus additional saving due to the increased availability during daytime of teams on call from home.

Sensitivity analyses (SA1–SA5) showed the impact of safety intervals. Tucker et al.⁶ implicitly assumed that all cases start immediately, while no staffing restrictions were applied. In SA3 we assumed cases started within 30 min after admission. Since time is required to transport the patient to the OR, SA3 closely approaches that assumption. Comparing results from SA3 with results from the basic scenarios showed that not accounting for safety intervals led to a higher demand for staff in order to maintain low percentages of patients not treated immediately. Hence, adopting safety intervals, as is done in this study, lowers staffing levels beyond those determined by methods such as described by Tucker et al.⁶ SA4 and SA5 show that extending safety intervals beyond what is medically reasonable leads to a further reduction of required staff. The same results also show that hospitals that have a similar case mix volume, but with a different composition from Erasmus MC's case mix, may have different staffing levels. We recommend that all hospitals determine appropriate safety intervals before deciding upon the required staff for night shifts. We also recommended that hospitals not rely solely on anesthesia billing records, since the latter do not account for safety intervals. Similarly, hospitals

Table 7. Proportions of Emergency Patients Treated Too Late Given Various Sensitivity Analysis Scenarios

Reference scenario	Safety interval	SA: Varying safety intervals					SA: Rec 23.00 h
		SA1 (%)	SA2 (%)	SA3 (%)	SA4 (%)	SA5 (%)	SA6 (%)
SC1	Total too late	12.0	12.8	23.3	7.8	3.4	13.4
SC1	Between 0 min and 10 min too late	3.2	3.5	4.8	2.2	1.1	1.7
SC1	Between 10 min and 20 min too late	3.5	3.8	5.8	2.8	1.1	4.2
SC1	Between 20 min and 30 min too late	3.5	3.5	6.5	2.1	1.1	5.6
SC1	More than 30 min too late	1.8	2.0	6.1	0.7	0.1	1.9
SC6	Total too late	14.6	15.5	27.4	9.6	4.5	15.6
SC6	Between 0 min and 10 min too late	3.1	3.3	3.9	2.3	1.3	1.3
SC6	Between 10 min and 20 min too late	3.5	3.8	5.0	2.7	1.3	4.1
SC6	Between 20 min and 30 min too late	3.4	3.5	5.8	2.4	1.5	5.9
SC6	More than 30 min too late	4.6	4.9	12.7	2.1	0.4	4.3

SC = scenario; SA = sensitivity analysis; Rec 23.00 h = recovery room occupancy at 23.00 h.

Table 8. Proportions of Emergency Patients Treated Too Late Given Various Sensitivity Analysis Scenarios

Reference scenario	Safety interval	SA: varying arrival intensity during the night						SA: likelihood of occupied ORs at 23.00 h			
		SA7 (%)	SA8 (%)	SA9 (%)	SA10 (%)	SA11 (%)	SA12 (%)	SA13 (%)	SA14 (%)	SA15 (%)	SA16 (%)
SC1	Total too late	10.6	10.4	10.4	11.9	11.7	11.7	9.7	13.2	7.5	15.1
SC1	Between 0 min and 10 min too late	3.0	2.7	2.8	3.2	3.0	2.9	2.4	3.6	1.9	3.9
SC1	Between 10 min and 20 min too late	3.3	3.4	3.2	3.3	3.5	3.2	2.9	3.8	2.3	4.3
SC1	Between 20 min and 30 min too late	3.1	3.2	3.1	3.4	3.4	3.3	2.9	3.9	2.0	4.6
SC1	More than 30 min too late	1.2	1.1	1.3	2.0	1.9	2.3	1.6	1.9	1.3	2.2
SC6	Total too late	12.7	12.4	12.2	14.3	14.6	14.8	11.7	15.6	9.4	17.8
SC6	Between 0 min and 10 min too late	3.0	2.6	2.8	3.0	3.0	3.0	2.3	3.6	1.9	3.8
SC6	Between 10 min and 20 min too late	3.3	3.3	3.1	3.4	3.6	3.2	2.8	3.8	2.5	4.3
SC6	Between 20 min and 30 min too late	3.3	3.2	3.3	3.4	3.3	3.4	2.9	3.8	2.2	4.7
SC6	More than 30 min too late	3.2	3.2	3.0	4.4	4.6	5.2	3.6	4.4	3.0	5.0

should not reduce staffing and extend waiting intervals without accounting for safety, as has been noted for some hospitals.²⁰

SA6 showed that recovery room occupancy at 23:00 h has some effect on the outcome, although the percentages of patients who would need to wait longer than 30 min remained within safe margins. Hence, decision-making in Erasmus MC was not affected by this modeling assumption. Nevertheless, hospitals that do have a substantial number of patients in the recovery room at 23:00 h should incorporate this in their modeling.

Several studies have shown that safety intervals or medical triage systems for emergency patients are hard to establish.^{4,21} In this study, we used safety

intervals determined by surgeons of Erasmus MC. We do not claim that these intervals are valid in general. However, establishing safety intervals facilitates medical decision-making on emergency patients.

A significant fraction of the cases performed during the night shift can be postponed to the day shift.²²⁻²⁴ Safety intervals help to identify cases that cannot be postponed. In future research, we will investigate the performance of a model with more precisely measured safety intervals. This would allow modeling the benefits of early treatment in terms of mortality and risks of complications for certain patient categories.

In the model we assumed transport or travel times between the OR and the ICU or the wards to be 30 min. Shortening of these times is likely to improve the

performance in all scenarios, which in the end allows for a further reduction of number of nurses required to be on call in the OR during the night.

In conclusion, this study shows that a discrete simulation model is useful in determining optimal size and composition of an emergency team, considering patient safety. Its flexibility provides for different input variables, such as safety interval frequencies, which might affect the outcome measures. Moreover, the approach allows evaluating different scenarios as a means to support complex managerial decision-making. Any hospital that reconsiders its staffing during night shifts should carefully consider the safety intervals of its patient mix. Using safety intervals, this model showed that at the test medical center it was possible to deploy fewer surgery and anesthesia nurses on call during the night without diminishing the quality of care.

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